AN INTERACTIONIST APPROACH TO THE FAMILY OF THE SUICIDAL ADOLESCENT

by

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DEDICATION

To my parents, my husband, and my little boys for their unfailing love and support.

ABSTRACT

Suicide is an increasingly significant cause of death among adolescents. What is known of the nature of the families of suicidal adolescents are only impressions garnered from basically demographic studies. The interactionist approach, which has yielded a wealth of information concerning the nature of schizophrenic and anorectic families, has not been applied to suicidal families. The purpose of this study was to develop a conceptual model, from an interactionist perspective, of the suicidal family and to explore that model using an abbreviated and revised version of the Family Task developed by Minuchin and his associates during their studies of delinquent and anorectic families. Since schizophrenia and anorexia nervosa, like suicide, are behavioral disorders common among adolescents, this study reviewed the relevant interactionist literature in those areas in the belief that there are important similarities as well as possible differences among all three families. Four volunteer families, two which previously contained a suicidal adolescent and two which did not, participated in this study.

The four videotaped Family Sessions were observed by the author and two independent raters who evaluated the families' interactions as they would have in a therapeutic situation. The results of their evaluations suggested the presence of such characteristics in suicidal families as joylessness or, alternatively, a pretended joy, and lack of attention and response to each other's expressions of emotion. It was concluded that the conceptual model of the suicidal family, advanced in this study and explored by the use of the Family Task, had the capacity for further development.

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Chapter 1: Introduction

> The point that I wish to emphasize is that inappropriate patterns exist during incipience and sometimes they are corrected and sometimes they are not. In the latter, a stressor will eventually introduce another stage of the crisis process...for the uncorrected and inappropriate pattern is the crux of family crisis.
>
> Jason Montgomery

It has been estimated that more than 100,000 Canadian adolescents will attempt suicide in 1983 (Cochrane, 1980). Scepticism is justified in the interpretation of these statistics. Self-Murder, the synonym for suicide coined by Abbe Desfontaines in 1737, has proven to this day to be a thorny concept to define. Haim (1974) discusses at length the challenges inherent in creating a construct which rests, in turn, on such other controversial concepts as rationality and volition. Where there is no agreed-upon definition of an event, it is reasonable to question whether the frequency of its occurrence can be accurately calculated (Faberow & Shneidman, 1961). There is as well the often-cited tendency of physicians, policemen, and coroners to shield the reputation of the suicide victim's family (Shneidman & Faberow, 1957; Shneidman, 1973). As a result, the number of deaths resulting from adolescent suicides is chronically under-reported. Despite the unreliability of these statistics, the high rate of adolescent suicide attempts is a very real concern for families, mental health professionals, and ultimately, us all.

Historically, the adolescent has been examined and treated as an individual person distinct from his family constellation. The vital influences on his developing psyche have been traditionally considered his to be emerging sexuality, his need for acceptance by his peers, and his struggle to achieve an independent identity (Coleman, 1974, 1980; Friedenberg, 1960; Matteson, 1975; Mitchell, 1974, 1975). The family system has been regarded as the backdrop before which the adolescent plays out his personal drama.

This perceived isolation has been especially true of the suicidal adolescent so that what knowledge there is concerning his family interactions amounts to a collection of impressions by researchers involved in fundamentally demographic studies of adolescent suicide. The overall effect of these impressions is to paint a picture of the suicidal adolescent as the passive recipient of bad parenting. This view of the suicidal adolescent, as a victim whose bizarre behavior is symptomatic of disease, is the traditional, linear, psychiatric approach to behavior disorders.

Jackson (1977-b) termed the viewpoint of the family researchers at the Mental Research Institute in Palo Alto as "interaction-oriented" (p. 2) because of their conviction that "symptoms, defenses, character structure and personality can be seen in terms describing the individual's typical interactions which occur in response to a particular inter-personal context" (p. 2). Jackson was quick to point out that the interactionist approach to behavior disorders was unique; it was neither a development nor a refutation of the linear interpretation. The interactionist regards the identified patient as an element in a disordered family system rather than as passive victim of forces beyond his conscious control.

The interactionist approach has been used in studies of the families of schizophrenic and anorectic adolescents. However, it has not been used to investigate the families of suicidal adolescents. If schizophrenic and anorectic behavior can be regarded as attempts to adapt to and thus survive in dysfunctional family systems, might not the same be true of suicidal behavior? Would an interactionist studying suicidal families (see Appendix 1 for an explanation of the use of this term) discover interactional patterns similar to those characteristically occurring in schizophrenic and anorectic families? Might there be interactions unique to the suicidal family and might such differences be more relevant than the similarities among all three families? Are the interactional patterns of suicidal families distinct from those of non-suicidal families? What could be the adaptive function of suicidal behavior within the family system? There are presently no answers to these interactionist-oriented questions.

The purpose of this study was to investigate suicidal families from an interactionist point of view using an abbreviated and revised version of the Family Task developed by Minuchin and his associates. The results and the discussions of those results are reported in chapters five and six, respectively, of this thesis.

Since the interactionist approach was developed through studying the interactional patterns characteristic of schizophrenic families, this study begins with a review of the relevant interactionist studies on schizophrenia. The interactionist approach has been further refined through a limited number of studies on the families of anorectics. These too are examined. The final part of the literature review is devoted to a discussion of the impressions of the suicidal family which emerge from the existing literature on suicide.

From the understanding thus gained of the basic interactionist approach as well as the apparent characteristics of suicidal families, a conceptual model of the suicidal family is offered at the conclusion of the literature review. The model suggests the nature of the interactions one would expect to find in a suicidal family.

There follows a discussion of the various interactionist approaches to family study, in particular the Family Task developed by Minuchin and his associates. It is this latter investigatory method which was chosen in this study to explore the conceptual model of the suicidal family. The results of that exploration form the concluding segment of this paper.

Chapter 2: Literature Review

> To study family process *per se* is difficult enough; to try to uncover the origins of pathology becomes part science and part crystal ball.
>
> D.D. Jackson

Part 1: The Interactionist Approach to the Schizophrenic Family

An interactionist regards the family system as distinct from and more powerful than the family members which compose it. Through a complex combination of checks and balances, the system struggles constantly to maintain its equilibrium or homeostasis. This tendency of all family systems to retain the old and resist the new is especially pronounced in dysfunctional families, which are more rigid in their patterns of interaction, less open to external input (Jackson, 1969-a; Minuchin & Fishman, 1981; Montgomery, 1981).

The homeostatic nature of the family system has profound effects on all its members. A family will close ranks against any member who appears to pose a threat to the maintenance of the system's equilibrium. Ackerman (1967) terms this response to personality variation, "intrafamilial prejudice".

> Among members of the same family group, there are elements of difference as well as sameness. Depending on the idiosyncratic emotional qualities of a particular family, symoblic meanings are attached to these differences which are then subjectively experienced by some members of the family as a distinct danger. The person showing the danger is felt to be an alien - the invasive stranger who threatens the security of the other members of the group" (p.51).

When this "invasive stranger" is a child, she can become the focus of the frustrations and hostilities of some or all family members, a process generally referred to as "scapegoating" (Ackerman, 1967). The child may be labeled the trouble-maker in the family and from that role a rule is formulated to the effect that the troublesome child is responsible for all family problems. If one child is designated the trouble-maker, another child may be chosen to bear the label "no trouble at all", the perfect child. In this way family myths are created which can persist through several generations (Ferreira, 1977). Again, scapegoating must not be interpreted as victimization. The scapegoated child often provokes the label of trouble-maker with genuinely bad behavior. Scapegoating is a dysfunctional family process, a "folie a famille" (Ferreira, 1977, p. 53) in which all family members play a part.

Frequently the scapegoated child attracts the favor and protection of some member of the family and these two form a coalition against the others (Minuchin, 1981). If that coalition involves (as it usually does) the child plus one of the parents, the boundaries which should exist between the generations will have been violated and a "perverse triangle" formed (Haley, 1977; Minuchin 1981). "In essence, the perverse triangle is one in which the separation between generations is breached in a covert way. When this occurs as a repetitive pattern, the system will be pathological" (Haley, 1977, p. 37).

In adolescence, the scapegoated child may become delusional, starve herself, or attempt suicide. As maladaptive as such behavior appears, its practical effect might be to unite the family at last in a common concern. In just such a convoluted fashion is the balance of energy within the system maintained. "All forms of mental illness must be regarded as logical adaptations to a deviant and illogical transpersonal system" (Selvini - Palazzoli, 1978, p. 193).

Although advances in knowledge never occur in a vacuum, the publication in 1956 of a paper entitled "Toward a Theory of Schizophrenia" by Bateson, Jackson, Haley, and Weakland marked a major turning point in the development of the interactionist approach. The impact of the original ideas contained in that paper - especially the double - bind theory - is still being felt; "there has been if not a scientific earthquake, at least a fair amount of commotion largely traceable to this work" (Weakland, 1977, p. 241).

Bateson (1972) expressed the view that all human behavior - speech, body movements, even silence - was communicative if done in the presence of others. In analyzing the confused verbalizations of schizophrenics, it struck him that this "crazy talk" was, in fact, a string of unlabeled metaphors. It appeared that the schizophrenic could not distinguish between the literal and the metaphoric. Haley suggested a possible linguistic application of Russell's Theory of Logical Types. Together, Bateson, Haley, and their associates hammered out these novel concepts beginning with their "Communication in Schizophrenia" project undertaken in 1952.

There are different levels of communication, each level modifying the other. When these levels are congruent, the message is readily understood by the receiver; when they are not congruent, the receiver experiences confusion, frustration, and rage (Watzlawick, Beaven, & Jackson, 1967). One communication level, which Bateson (Haley, 1969-a) termed the "report", consists of the actual informational content of the message. Correct word usage (semantics) and word order (syntactics) will promote clarity in this regard.

At a second level of communication, which Bateson (Haley, 1969-a) termed the "command", each participant in the conversation attempts to control or suggest a change in the relationship between himself and the receiver of his message. He who succeeds in defining the relationship has, in a sense, succeeded in defining himself and reaffirming the validity of his own existence. When the student says to her teacher "I don't understand this division", there is more involved than her admission of helplessness in the face of mathematical complexity: she is also asserting that there exists between herself and the teacher a relationship which necessitates that the teacher feel concern for her student's difficulties and take steps to remedy the situation. While the student may have to stay after school for extra help, she will have won the relationship struggle (Haley, 1969-a). The teacher may, of course, reject the student's definition of their relationship by indicating that she is neither concerned nor willing to provide additional instruction. Lastly, the teacher may ignore the attempted definition by communicating to the student that, in fact, no relationship can exist between them because the student doesn't exist (Selvini-Palazzoli, 1978). This is commonly accomplished through non-verbal means such as refusing eye contact or pretending not to hear.

Thus the context in which the message is embedded determines whether it is to be understood as, say, a joke or a threat. Clearly, "I hate you" spoken in a playful manner with an affectionate tone of voice delivers a far different message from the same words spat out angrily and accompanied by a slap. Bateson et al. (1969) concluded that the distinguishing characteristic of the schizophrenic was his inability to determine the intended purpose of both the messages sent to or received from others or even the thoughts which jumbled through his head. "He must live in a universe where the sequences of events are such that his unconventional communicational habits will be in some sense appropriate" (Bateson et al. 1969, p. 35).

Bateson's supposition was that the schizophrenic had endured repeated exposure to interactions in which it was impossible to rely on contextual clues. Psychiatrists had long noted that visits from the patient's family (most often the mother) upset the schizophrenic and interfered with his treatment (Hill, 1955). Bowen (1960) recounts the story of the mother of the schizophrenic who, while angrily berating her son for his lack of independence, was busily cutting his meat and buttering his bread. She was surprised when he stopped eating! For this "unreasonable sequence of experiences" (Bateson et al. 1969, p. 35), the term coined was the "double-bind", the essential elements of which are:

1. "The individual is involved in an intense relationship; that is, a relationship in which he feels it is vitally important that he discriminate accurately what sort of message is being communicated so that he may respond correctly" (Sluzki, Beavin, Tarnopolsky, & Veron, 1977, p. 211).
2. "The individual is caught in a situation in which the other person in the relationship is expressing two orders of message and one of these denies the other" (Sluzki et al. p. 211). This is not a one-time occurrence, but the predominant pattern of interaction between them.
3. "The individual is unable to comment on the message being expressed to correct his discrimination of what order of message to respond to...". (Sluzki et al. p. 211). The reception of incongruent messages is not unique to the schizophrenic. Often, during

the course of conversation, one person will say to another: "I'm not sure just how to take that last remark." or "For someone who insists he isn't angry, you sure look mad." These attempts to clarify communication are termed "metacommunication" (Bateson et al. 1969) and they are essential if people are to properly understand one another. It is the right to metacommunicate which the schizophrenic is denied for to challenge the messages he receives is to challenge a relationship he cannot afford to lose (Scheflen, 1980).

4. Nor can he escape the field thereby possibly exposing himself to more congruent interactions (Watzlawick, 1969). Despite his frustration and despair, his dependency on the continuation of the relationship binds him as securely as a spider's web binds a fly.

To continue the former example of double-bind behavior, if the schizophrenic young man asserts his independence, seizing the utensils from his mother and insisting on his right to feed himself, his mother will rebuke him for his ingratitude in response to her efforts to help him. If he allows her to cut his food, she will continue to chastise him for his childish ways. Should he dare to tell her that this "no-win" situation is driving him crazy, she could turn her back on him, withdrawing the affection which he craves. Caught in this double-bind and unable to leave the field, the schizophrenic might choose to talk and act "crazy" so that medical attendants will dismiss his mother and remove him to a cool, quiet room where he can retreat into a drugged sleep. If the particular form of craziness he chooses is to act hostile and suspicious, or to giggle and grimace incessantly, or to withdraw into a shell, he will be diagnosed as paranoid schizophrenic, hebephrenic schizophrenic, or catatonic schizophrenic, respectively (Bateson et al. 1969).

5. As in all behavioral conditioning, eventually any part of the double-bind sequence will be sufficient to provoke rage and despair in the individual (Bateson et al. 1969).

While it is impossible to omit the relationship component of messages, it can be undermined. The distinguishing characteristic of the schizophrenic's communications is that he constantly disqualifies his own messages in an attempt to avoid making a relationship statement (Haley, 1969-a). He does so by denying that he is transmitting any message to anyone at this time and in this place. He may assert that he is Napoleon, or talk in gibberish, or imply that the receiver is an enemy agent, or that the conversation is taking place on a space station. "It seems apparent that the list of ways to avoid defining a relationship is a list of schizophrenic symptoms" (Haley, 1969-a, p. 160).

One of the axioms of communication expounded by Watzlawick et al. (1967) was that "all communicational interchanges are either symmetrical or complementary depending on whether they are based on equality or difference" (p. 70). Participants in symmetrical conversations mirror each other's strengths and weaknesses; those in a complementary interchange function as halves of a whole with one participant assuming a "one-up" position and the other, the "one-down". Both forms of communication will become pathological if they are the only ways in which the participants can interact. A symmetrical relationship may escalate through competitiveness into open hostility; a complementary relationship may be inappropriately demanded where it was once provided freely.

As interactions descend into pathology, achieving control of the relationship takes increasing precedence (Sluzki & Beavin, 1977).

> In fact, it seems that the more spontaneous and healthy a relationship, the more the relationship aspect of communication recedes into the background. Conversely, "sick" relationships are characterized by a constant struggle about the nature of the relationship; with the content aspect of communication becoming less and less important (Watzlawick et al, 1967, p. 52).

Spurred on by Fromm-Reichman's (1948) delineation of the "schizophrenogenic mother", psychiatry discovered, in turn, that schizophrenics were part of a family constellation which seemed somehow implicated in their disease (Lidz, Fleck, Alanen, & Cornelison, 1963).

The mother of the schizophrenic has been cast in the unenviable position as "the dominant parent whose pathological influence on the child is not sufficiently counteracted by the typically weak, rather withdrawn father" (Watzlawick, 1969, p. 73). She appears to be a rather vacuous woman, superficial and flirtatious, the kind of woman who can fish for compliments and boldly assert that her family is problem-free while her schizophrenic son lies sedated in a psychiatric ward (Hill, 1955). Yet she is, in reality, domineering and manipulative, especially towards men, whom she despises in general (her husband in particular) for their weakness.

Although she grandly insists that she married for love, she married only to escape her own domineering mother to whom she remains emotionally bound (Hill, 1955). Her feelings for her schizophrenic child have been mixed since his conception, which was intended to grant her the womanly fulfillment denied to her in marriage (Wynne, Ryckoff, Day, & Hirsch, 1958). From the beginning, her pregnancy was fraught with fears of miscarriage, stillbirth, and deformity which lead her to frequently contemplate abortion rather than awaiting the seemingly inevitable (Hill, 1955). The child's birth was accompanied by an increase rather than a lessening of marital tension and often occurred during the parents' first separation. The newborn demanded and received special care from the mother either because he was her first born or a sickly infant or because he occupied a position of privilege such as the first male child (Bowen, 1960; Lu, 1962). She has always felt a special relationship with this child who seemed to need her more.

As the child grew, so did the mother's ambivalent feelings. She overcompensated for the anxiety and resentment aroused in her by the traditional maternal role by a smothering, overprotectiveness (Jackson, 1969-b).

> This love is idealized, romantic and unrealistic and leads to extensive denial of anything they observe in the child contrary to their fantasies concerning him. The result is, of course, disastrous to the child, but it does not follow that the mother meant it to be so; she meant to destroy only what we would regard as the naturalness, the normal badness, the spontaneity, the investigative

> curiosity, the boldness of her child so that she could keep it good and ideal and completely her own (Hill, 1955, p. 109).

The mother is never able to accept the child's separate identity (Alanen, 1960). The mother-child relationship becomes a compulsory one in which the implied message is "remain symbiotically related to me" (Watzlawick, 1969, p. 77). When he becomes an adolescent, the child's normal struggle for independence challenges this symbiosis. As Bowen (1960) expresses it: "It takes a lot of doing to hold your mother's hand and play baseball at the same time" (p. 367).

The child learns from this relationship - "the most important in his life and the model for all the others" (Bateson et al. 1969, p. 44) - that he cannot trust his own perceptions of reality. "This means that he must deceive himself about his own internal state in order to support mother in her deception. To survive with her he must falsely discriminate his own internal messages as well as the messages of others" (Bateson et al. 1969, p. 42). Above all, he must never challenge the relationship which entwines his mother and himself in a morass of pretense and denial.

The father of the schizophrenic is usually characterized as a weak, passive man who is as much a victim of his emasculating wife as is his child (Bowen, Dysinger & Basamania 1959; Haley, 1969-a). He has been denied the authority and prestige usually granted the head of the house because of his failure to fulfill his wife's marital expectations. She treats him with contempt, openly defying and ridiculing him in front of the children (Lidz, Cornelison, Fleck, & Terry, 1957; Morris & Wynne, 1965). Some fathers of schizophrenics pretend to be tyrants; they pout and they rage but with little effect (Farina, 1960; Garmezy, Clarke, & Stockner, 1961). They frequently resent their schizophrenic child for seizing the lion's share of the wife's attention and reject him cruelly (Lennard, Beaulieu, & Embry, 1965; Lidz & Fleck, 1960; Lidz, Parker, and Cornelison, 1956).

The behavior of the schizophrenic family is pervaded by the members' fear of relating. The parents are immature, inadequate personalities whose energies are consumed by their fractious marital relationship (Baxter, Arthur, Flood & Hedgepath, 1962; Bowen, 1960; Haley, 1960). Although commonly described as "emotionally divorced", it is doubtful whether the husband and wife were ever truly emotionally united. Neither spouse has completed the separation from his parents. Their loyalties remain with their families of origin (Lidz et al. 1957). Rosenbaum (1961) describes the marriage as "a brittle attachment" (p. 124), so tenuous in fact that neither partner dares set rules for the other.

Apparent attempts at leadership are immediately disqualified (as is all other communication) by either the person making them or others in the family. Nor is any family member willing to accept the blame for these family decisions which just seem to happen. The mother chronically protests her innocence. The father may quibble or protest or even appear to be blaming his wife but in the end, he will have so disqualified himself that the issue of blame will remain unsettled (Haley, 1969-a).

The parents alternate between being over-solicitous and unresponsive to their children's emotional needs, a behavior Rosenbaum (1961) terms "selective inattention" (p. 119). The children's affections are courted but only so that they may be used by their parents as pawns in the marital game.

Coalitions within and without family boundaries are forbidden as acts of disloyalty. Thus the experiences of both parents and children are restricted to the psychotic interactions which occur within the family. "All of the qualities of disordered thinking and interpersonal relations which have been described for the individual schizophrenic have recognized counterparts in his family" (Rosenbaum, 1961, p. 120).

The interactionist approach has contributed much to our understanding of the relationship between family interactions and individual behavior. It has freed therapists from analyzing undesirable behavior patterns in terms of victims and victimizers. We will now consider the family system of the anorectic which has also been studied from an interactionist perspective.

Part 2: The Interactionist Approach to the Anorectic Family

Anorexia Nervosa is a behavioral disorder that primarily affects adolescent girls (Selvini-Palazzoli, 1978). It is characterized by a loss of more than 25 per cent of normal body weight, cessation of menstration, hyperactivity, and extreme sensitivity to cold (Minuchin et al. 1978). Its victims appear to be engaged in a power struggle with the parents which focuses on the adolescents' eating habits and ultimately on their weight. Although reduced to mere skeletons, these young girls view themselves as grotesquely fat. They engage in frenzied physical activity despite a sharply-reduced caloric intake and refuse food despite the frantic pleas of their families.

As with schizophrenia, there are a number of theories on the etiology of anorexia nervosa. With the exception of the work done by Minuchin et al. (1978) and Selvini-Palazzoli (1978), anorexia nervosa has not been studied from the interactionist perspective. Selvini-Palazzoli was much impressed with Haley's (1969) model of the schizophrenic family. She applied that model as a measure of the pathology of the anorectic family after becoming discouraged with traditional approaches.

Minuchin's interest has always been in the shifting structures of the family; its coalitions and the rigidity or permeability of its subsystem boundaries. He considers a family with weak boundaries which spill over into each other, frequently crossing generational lines, to be a dysfunctional family, "a system which has turned upon itself, developing its own microcosm" (Minuchin et al. 1978, p. 77). Because Minuchin has developed a different vocabulary, he may appear to the reader to be interpreting family dynamics from a perspective other than that of the interactionist. That difference, however, is more illusory than real for in discussing such concepts as "enmeshed" and "disengaged" families, he is quick to point out that the distinction between the two lies in their transactional styles. "Family transactional patterns form the matrix of psychological growth" (Minuchin et al. 1978, p. 52).

There are important differences between schizophrenic and the anorectic families. Unlike the schizophrenic family with its "fatuous drawing-room attitude" (Selvini-Palazzoli, 1978, p. 204), the anorectic family is clearly concerned and upset. From a therapeutic standpoint, this emotional involvement is an obvious strength. Nor are the communicational patterns in the family of the anorectic as disturbed as those of the schizophrenic. While there is a great deal of rejection of the content and particularly, the relationship implied in messages, there is little disconfirmation of the sender (Selvini-Palazzoli, 1978). The receiver is saying, in effect, as Lord Chesterfield did: "I don't agree with what you say but I will defend to the death your right to say it." Because the members of the anorectic family do not feel compelled to continually disqualify their own and other's remarks, their speech is coherent and flowing. The schizophrenics family's fear of relationships causes them to shun coalitions. However, secret alliances which violate parent-child subsystem boundaries, are the hallmark of the anorectic family (Minuchin et al. 1978).

Both parents of the anorectic view themselves as martyrs who have surrendered their personal happiness for the common good. The mother is a fine cook and housekeeper who appears thoroughly devoted to her family's welfare. In actuality, she is fretful, over-protective, and inclined to be bossy (Wall, 1959; Warren, 1968). The father protests that his only failing is perhaps an inclination to be too understanding and forgiving. His children, on the other hand, regard him as quietly demanding and withdrawn (Blitzer, Rollins, & Blackwell, 1961; Tolstrup, 1975).

The parents' symmetrical communication patterns are, in fact, a contest to determine who has suffered more in the marriage. Selvini-Palazzoli refers to this process as "symmetry through sacrificial escalation" (p. 214).

Like schizophrenic parents, the anorectic parents' loyalties remain with their families of origin. The subsystem boundaries which should exist between parents and grandparents are almost non-existent. The marriage is a sterile one in which the over-riding concern of both partners is that they appear blameless in the eyes of the world.

The marital conflict so apparent in the schizophrenic family is suppressed and denied by the anorectic family, although it clearly bubbles just below the surface and has repercussions for all family members (Minuchin, Baker, Rosman, Liebman, Milman, & Todd, 1975). The schizophrenic mother will disqualify a leadership statement, such as "Go do your homework" with an aside directly aimed at her uninvolved spouse: "Your father doesn't care whether you fail, but I do". The anorectic mother's attack is disguised as wifely submissiveness: "Your father wants you to pass." Her pretense of assuming the one-down position in the marriage assures her of getting her way with a minimum of opposition. Despite these differences in transactional styles, the anorectic mother is as dominant an influence as the schizophrenic mother (King, 1963).

It is their overwhelming concern for appearances which prevents the frustrated and unhappy marital partners from seeking support from sympathetic friends and relatives.

> As a result, the system of alliances and the search for an arbitrator are kept within the family and focused especially on the patient, who is secretly encouraged to side with the more persecuted of her two parents. But since each of the parents sees

> himself in that role and since the patient depends on both, she occupies an extremely ambiguous position in the system. This ambiguity is complicated further by the fact that though the two parents vie for her support, neither is prepared to enter into an open alliance with her since, paradoxically, that alliance would detract from their professed roles of being the more downtrodden of the pair" (Selvini-Palazzoli, 1978, p. 214).

This is the double-bind for the anorectic child; she cannot ally herself with either parent nor can she refuse to do so.

Minuchin et al. (1978) describe three marital tension defusers used interchangeably by parents and children in anorectic families. In "triangulation", one parent pressures the child to side with him against the other. Alternatively, the child may take the initiative and ally himself with one parent in a coalition against the other.

Selvini-Palazzoli (1978) terms these solutions "three-way matrimony" (p. 211). Lastly, when the anorexia is full-blown, the parents may unite in a common concern for their child. "In some families, the parents require the children to reassure them that they are good parents or to join them in worrying about the family... . In most cases, parental concerns absorb the couple, so that all signs of marital strife or even minor differences are suppressed or ignored" (Minuchin et al. 1978, p. 33).

The anorectic child learns that only a narrow range of behaviors will be tolerated in her family before homeostatic mechanisms come into play. She will be rewarded to the extent that she resembles her parents and assumes their values and aspirations; she will be ostracized if she insists on her right to individuality. She strives constantly to be the perfect child, her parent's "dream baby-hero" (Hill, 1955, p. 68) and she becomes an expert "parent-watcher" (Minuchin et al. 1978, p. 59) who anxiously scans the parental horizon for signs of displeasure. To dare to grow up, to even contemplate breaking free of the familial cocoon, to assert uniqueness - is to risk losing everything she values. For her, as for the schizophrenic, the implied directive is "to remain symbiotically attached" (Watzlawick, 1969, p. 77).

It is not surprising that such a child might fasten on her physical functioning as the battlefield for her independence. In her enmeshed family, where everyone's personal boundaries are violated, her parents struggle to possess her body as they possess the rest of her. Her vomiting and purging habits become topics of conversation at the dinner table but the child knows her refusal to eat punishes and controls her parents as nothing else can. She also realizes, at some level, that if she persists in starving herself, she will indeed escape the field - through her own death. "Illness may become her identity card" (Minuchin et al. 1978, p. 61).

In anorexia nervosa, as in schizophrenia, the interactionist focuses on the family system when he seeks the cause of the adolescent's self-starvation. Such a systems orientation has not yet been adopted in assessing suicidal families. What we do know of the interactions which are characteristic of such families amount to impressions garnered from largely demographic studies of suicide. It is to these we now turn.

Part 3: Impressions of the Suicidal Family

The fragmentary evidence, concerning the nature of the suicidal family, which is found in the literature creates an overwhelming impression of emotional numbness. Death, despair, and discord seem to have stalked the family since its inception. (Jacobziner, 1965; Shaffer, 1974; Tishler, McKenny, and Morgan, 1981). In a study by Tuckman and Youngman (1964) of the families of adolescent suicide attempters, more than half of the families were well-known to social agencies because of past problems involving abandonment, unemployment, child abuse, delinquency, parental suicide, and alcoholism. Hendin (1975) dismisses the supposedly normal adolescent preoccupation with death (Haim, 1974) with the comment that "fascination with death is often the climax of having been emotionally dead for a lifetime" (p.328).

The mother of the suicidal adolescent is generally described as an immature, emotionally unstable woman who has never adjusted to leaving her parental home (Faigel, 1966; Glaser, 1965). She has found both marriage and motherhood disappointing. Frequently, the mother in the suicidal family has reacted to her failed marriage and the unwelcome burden of motherhood by rejecting her child either indirectly through separation associated with alcoholism or mental illness (Glaser, 1965) or directly, by abandoning the child to the care of relatives or social agencies. Alternatively, she may have been motivated by guilt to hide her hostility and despair behind a facade of rigid control (Schrut, 1964).

The cost of maintaining such control is great. The mother takes no pleasure in her children; everything is done out of a sense of "joyless duty" (Hendin, 1975, p. 329). In order to survive with her, the children are required to be "quiet drones" (Hendin, 1975, p. 329) dwelling in a home where love is only pretended. This lack of intimacy and true caring among family members is described by Gould (1965) as a "loss of love". "It is my feeling that the core factor in the formation of a suicidal personality in children and adolescents is this felt loss of love" (p. 234).

While concluding that ambivalent maternal feelings will not have the same devastating effect on the child's emotional development as outright rejection, Schrut (1964) cautions that the child, in realizing how little pleasure he brings his parents, may "feel himself unworthy and deserving of neglect and punishment, especially in the case of the unrelentingly depressed mother whose self-rejection is seen by the child as a rejection of him" (p. 1104). Richman (1978) considers the roots of maternal ambivalence as lying in the mother's fear of losing herself through merging with her child as contrasted with the guilt and pain she experiences by rejection.

> Closeness cannot be tolerated in part because of the threat of loss of identity and distance is untenable due to the threat of the loss of symbiosis....Unfortunately, the disengaging, or rejecting, or turning away usually occurs during a crisis just when support and contact are most needed, occurring in those with the greatest need for belonging (p. 143).

Generally the father, as well, in the suicidal family is frustrated and unhappy with his parental role. He has responded to the responsibilities of fatherhood by becoming coldly critical and demanding especially toward his sons (Bakwin, 1957; Mc-Anarney, 1979; Randall, 1966). More commonly, he has deserted the family altogether. Loss of a birth parent through abandonment or divorce is a characteristic of suicidal families (Dorpat, Jackson, & Repley, 1965; Jacobs & Tercher, 1967; Jacobziner, 1965' Perlstein, 1966). The father may also be absent from the home because of death, imprisonment, or commital to a mental institution (Randall, 1966; Tishler, McKenney, & Morgan, 1981). Jacobs (1971) regards the loss of a parent, for any reason, before the child is 12 years of age, as predisposing the child to suicidal behavior.

Many suicidal families are plagued by parental quareling, separation, and divorce. There is frequently a succession of men in the mother's life, all of whom seem to be immature, emotionally unresponsive people incapable of sustaining a satisfactory relationship with either the mother or her children (Jacobs, 1971). There are frequent moves and school changes, as the family leaves behind a trail of broken relationships (Bakwin, 1966; Jacobs, 1971).

Alternatively, the unhappy parents may feel compelled to remain together for the children's sake or to maintain appearances. They may choose to go through the motions, fulfilling their public duties as parents and spouses while remaining emotionally divorced or they may quarrel openly, with one or both spouses continually threatening to leave (Margolin & Tercher, 1968).

Marks and Haller (1977) draw a profile of the suicidal male adolescent as a tense, anxious, overly-dependent youth resentful of his mother and emotionally estranged from his father. They depict the suicidal female adolescent as depressed and unstable, isolated from both parents but particularly fearful of her cold, rejecting father. The almost infantile dependence of adolescents, who attempt suicide, predisposes them to be especially frustrated and enraged by their unloving environment although many are unaware of their anger and most are unable to express it constructively (Marks & Haller, 1977; Tabachnick, 1961). Suicidal adolescents generally have a history of venting their hostility through truancy, delinquency, and running away from home (Jacobs & Teicher, 1967). They view their family as a "jail in which everyone is in solitary confinement, trapped within their own particular suffering" (Hendin, 1975, p.338).

Such is the impressionistic evidence concerning the nature of the suicidal family. How would an interactionist describe the behavior patterns which exist between the members of a suicidal family? How would he interpret the marital strife or the mother's ambivalent feelings toward her child? We now turn our attention to the development of a conceptual model of the suicidal family from an interactionist point of view.

Chapter 3: A Conceptual Model of the Suicidal Family

> Often we infer a kind of race to see
> who will use the weapon of suicide
> first.
>
> W. Tabachnick

The schizophrenic family and, to a lesser extent, the anorectic family, have been examined using an interactionist approach. The suicidal family has not. An interactionist should be able to predict, with some certainty, the nature of the interactions likely to be found in any reasonably representative sample of either schizophrenic or anorectic families. It would be inaccurate at this stage in the development of the interactionist approach to describe such a sampling as random (Haley, 1969-b). An interactionist could not, however, make such an accurate prediction of the interactions likely to occur in suicidal families; a conceptual model of the suicidal family, from an interactionist perspective, is lacking.

In order to develop such a model, a researcher must find a way to marry what the interactionists have uncovered in their studies of schizophrenic and anorectic families with the impressions of suicidal families which can be gleaned from non-interactionist-oriented studies on suicide. Such an attempted marriage is fraught with difficulties.

Scientists have told us that observation is an active rather than a passive process. It follows that what is observed in a family will depend to a great extent on what the observer is looking for. His point of view will determine not only the behavior he singles out, but what interpretation he places upon it. The confirmed interactionist will be predisposed to finding disturbed interactional patterns in any family he observes.

Those who have studied suicide, and, incidentally, the suicidal family, have not been interactionists. They may have ignored or dismissed as unimportant such characteristics of family transactions as repeated disqualifications in communication or rigid parent-child coalitions which an interactionist would have fastened onto at once.

Alternatively, they may have selected such behaviors for attention but given them a different interpretation. It is hazardous, therefore, to attempt to develop a conceptual model of the suicidal family couched in interactionist terms with only these impressionistic studies to rely on.

The interactionist research on schizophrenic and anorectic families is useful in the development of such a model but it too can be used only with caution. While it is assumed, in this thesis, that there may be some features common to the schizophrenic, anorectic, and suicidal families, there may also be differences and those qualities which are unique to the suicidal family may, in the end, prove to be the critical ones.

Interactionists believe that, in the presence of others, human beings cannot avoid communicating and since every communication contains a relationship element, it follows that human beings also cannot avoid relating. In studying a family group, the interactionist will focus his observations on the nature of the relationships which exist among the family members.

The members of both schizophrenic and anorectic families have difficulty establishing mutually acceptable definitions of their relationships. For purposes of simplification only, I will focus on the relationship between mother and child. The schizophrenic has grown up in a family in which his mother has given him continual, incongruent definitions of the relationship she wants to have exist between them. In the classic example, she opens her arms to her child only to cringe on his embrace. The relationship component of her communication reflects a conflict. Does she want her son to accept that theirs is a loving mother-child relationship in which hugging is in order or does she want him to recognize her lack of motherly feeling and respect it by maintaining his distance?

Because the child feels he cannot inquire as to her meaning i.e. metacommunicate, he does not know to which relationship message he should respond. Unable and/or unwilling to abandon his frustrating interactions with his mother by, say, leaving in search of more congruent communications, the child eventually discovers that he can escape the field through madness. He attempts to avoid the entire relationship issue but the end result, as Haley (1969-c) indicates, is that he will be hospitalized and a doctor-patient relationship will be enforced upon him.

The anorectic child must also cope with her mother's conflicting definition of their relationship. On the one hand, the mother communicates to her daughter that she is an exceptional child with the implication being that the daughter will naturally develop into a strong and independent woman capable of making her own way in the world. On the other hand, the mother simultaneously communicates to her daughter that theirs is a relationship in which the mother wants and needs her child to remain always dependent, grateful, obedient, and a comfort to her. Unable to either metacommunicate or leave the field, the daughter chooses to stop eating as a way of avoiding her mother's definition of the relationship. However, self-starvation, like schizophrenic behavior, generally leads to hospitalization and the imposition of the doctor-patient relationship.

Despite the superficial similarities in the scenarios of the schizophrenic child and the anorectic child, there are important differences, as was indicated in the literature review, in the interactions which occur in their respective families. As Haley (1969-c) comments, the schizophrenic family is unique in that its interactional characteristics are so pronounced and consistent. "In the family of the schizophrenic the range of behavior is as limited and inflexible as is the behavior of the schizophrenic in contrast to other people" (p. 197).

Such consistency in pathology is not a characteristic of the anorectic family. Selvini-Palazzoli (1978) distinguished between the communicational patterns of strictly anorectic families and those families in which the identified patient alternated between anorexia and bouts of bulimea. The latter, she found to be more pathological than the former in that they not only rejected communications but disconfirmed the sender. It follows that any particular anorectic family may not show the same degree or even kind of behavioral problem as another.

A similar variation in degree and type of pathology should also be characteristic of the suicidal family. Suicidal behavior can be interpreted as covering a wide range of activities from swallowing water from an iodine bottle which has been previously carefully rinsed to putting a gun to one's temple and pulling the trigger. Without an acceptable definition of suicidal behaviors, can an adolescent who rams his car into a cement wall be considered a suicide and should his family be labeled suicidal? The wider the range of behavior which may eventually be definitively termed suicidal, the greater the likelihood that all degrees and kinds of pathology will be found within the category of suicidal families.

In those suicidal families in which love is only pretended, one would expect to find family members routinely disqualifying their own and others' communications. The cold, controlling mother undoubtedly delivers inconsistent relationship messages to her child. One would be that she is a mother who genuinely cares for her child and delights in him. The other message, however, would be that she is bound to him only by duty and circumstance and that he brings her no pleasure. Such a mother would act very much like the mother of the schizophrenic i.e. alternately seeking and withdrawing from physical contact with her child.

The literature suggests that there is another category of suicidal family in which no one bothers to fake affection. The open hostility between the parents has either ended, or routinely threatens to end, in the dissolution of the marriage. The child is given the clear and unambiguous message that, if it were not for him, his parents would not have married and/or would have long since separated. It is not a great logical leap for the child to conclude that his parents would be happy if he were dead. The relationship message transmitted to him is that he does not or, at least, should not persist in living. Selvini-Palazzoli (1978) labeled such a message, the ultimate disconfirmation. This is a reasonable interactionist explanation for the observation of Schrut (1964) that the child is better able to cope with ambivalent maternal feelings than such unrelieved rejection.

There should be an almost palpable tension between the spouses in a suicidal family. The literature indicates that such families frequently have a long history of unresolved marital conflicts; they are well-known to social agencies for problems with wife abuse, desertion, and non-payment of support monies. The spouses' quarelling may be open, as in the schizophrenic family, or suppressed and denied, as in the anorectic family, as not being tolerable behavior in a proper home.

The weak parental coalition should predispose one or both parents to ally with a favoured child against the other spouse. Alternatively, the coalition could be with a parent or sibling of the spouse. The literature suggests that the parents' continued attachment to their families of origin sets a pattern of weak subsystem boundaries.

One would expect the mother in the suicidal family to be cold and domineering although she may operate behind a facade of loving concern. The father, on the other hand, should appear passive and detached although he is actually stern and unyielding (especially with his male children). The presence of a controlling mother and an uninvolved father is virtually axiomatic in dysfunctional families.

In the suicidal family, matters of control and conformity are given great importance. Any child who rebels, will likely be scapegoated. That scapegoated child will not necessarily be the one with the suicidal behavior. A child with enough self-confidence to rebel against a strong-willed mother may be a child with enough courage to escape the field by some means other than suicide. However, a child whose rebellious spirit is crushed, may be that more easily overwhelmed by unsatisfying family interactions.

While the suicidal family might give the initial impression of being enmeshed, on closer examination, it should be apparent that its members are disengaged at an emotional level. They may practice "selective inattention" (Rosebaum, 1961, p. 119) to family members' emotional needs, over-responding to some while ignoring others.

The final characteristic of the suicidal family should be the easiest to observe; it is the sense of joylessness referred to by Hendin (1975). Whether the family has stayed together because of guilt or openly split, the frustration and disappointment family members experience in their interactions should be apparent. Hendin (1975) described the members of the suicidal family as already dead; all that remained was to bury the bodies.

A passible scenario would involve two young, immature persons forced to marry because of an unplanned pregnancy. The husband and wife remain emotionally attached to their own parents or siblings, never successfully uniting as a couple. The resulting children are unplanned and/or unwanted.

The family will break apart or stay together "for the children's sake". In either event, the parents' bitterness and frustration is there to observe. The mother will reject her children outright or pretend an affection and loving concern which she does not feel. The clear message received by a child in such a family is that his continued existence is causing everyone, including himself, great unhappiness.

There are several approaches an interactionist might use to examine such a conceputal model. We will now consider some of these exploratory methods especially the Family Task which was the chosen method in this study.

Chapter 4: Methodology

> If there were a satisfactory descriptive system for families, questions like the following might ultimately be answered: Does the delinquent come from a particular kind of family....Is the family containing a schizophrenic different in any important way from the family which contains a psychopath or alcoholic? Is there a "normal" family system which could be differentiated from one where psychiatric symptoms exist or are likely to occur?....The crucial differences between families would seem to reside in the sorts of transactions which take place between family members; the study of differences becomes a classification of communication patterns in the family.
>
> Jay Haley

Part 1: Interactionist Approaches to Family Study

At the present time, it is more accurate to categorize an analysis of family interaction as an investigation, rather than as an experiment. Until the labels of individual psychopathology are replaced by terms which specifically describe the behaviors of different types of families, the labeling of any particular family as schizophrenic or suicidal is not justified.

The delineation of those specific behaviors requires a generally-accepted theoretical base. There is, for instance, no agreed-upon definition of schizophrenia. Is it a disease or a syndrome? Can a schizophrenic cease to be schizophrenic after treatment or does he merely become a schizophrenic in remission? Should schizo-affective, schizoid, and autistic behaviors also be classified as schizophrenic? The list of questions which remain unanswered about one of the earliest identified and most debilitating of mental disorders is endless.

If we assume that family systems will differ from each other if any one member is systematically behaving

> differently within the family and further assume that the pre-schizophrenic, the overt schizophrenic, the remitted schizophrenic and the schizoid are systematically behaving differently from each other, then it would follow that within the category "schizophrenic family" there would be at least four different types of family system. These types would be in addition to the possibilities of sub-species of families based on the presence of different types of overt schizophrenia. (Haley, 1969-b, p. 268)

Such a precise classification of either schizophrenic or suicidal behavior does not now exist. The basic principles of family interaction have been gleaned from studying families termed schizophrenic because of a diagnosis, which may be arguable, of only one member. Every researcher who has labeled a specific family interaction pathological has made that characterization on the basis of his own assumptions regarding the nature of the disorder. Thus the psychiatrist responsible for the original diagnosis of the identified patient and the investigator looking for causes of that behavior in the patient's interactions with his family may be working from two different vantage points, neither of which is correct.

Again, there is no generally-accepted definition of a suicidal family. If an adolescent has only threatened suicide, can the family be considered suicidal? If the adolescent has committed suicide, does the family continue to bear the suicidal label as far as the remaining children in the family are concerned? Until there is an accepted method of classifying families, it is indefensible to speak of having a random selection of any one type (Haley, 1969-b).

Nor is there agreement today on what constitutes a family. If a child lives part of the time with his mother and grandmother and the rest of the time with his father, his father's girlfriend and her two children from a previous marriage, which group should be considered his family or does he have two families? If that child becomes schizophrenic or suicidal as an adolescent, which family should be labeled? If some future offspring of the father and the girlfriend becomes anorectic, would that family grouping bear the labels of two different psychopathologies? Insisting that all families chosen for an experiment be traditional ones composed of two parents and the children of their union may result in a prejudiced sample (Haley, 1969-c) i.e. broken homes are the norm for the families of suicidal adolescents. Interactionists have "examined rather than solved" (Haley, 1969-b, p. 271) these sampling problems.

Family investigations are based on certain assumptions about families such as that their behaviors form rule-governed patterns stable over time which profoundly affect the development of family members. However, there is no way of knowing at present whether the family behavior observed is the result of the presence of the identified patient or even relevant to his disorder (Riskin, 1969). It is assumed that such pathological family interactions predate the development of the identified patient's disease and that his bizarre behavior is an adaptive response to that family pattern (Riskin, 1969; Selvini-Palazzoli, 1978).

Haley (1969-b) characterizes family experiments as descriptive rather than inferential. The ultimate responsibility for unraveling and identifying the multitudinous interactions which occur among the members of the experimental family rests with the trained observer. Keeping in mind that each interaction consists of several levels of meaning, the analysis can only be as skillful and sensitive as the observer himself. It is inevitable that the analysis will reflect not only the observer's knowledge and experience but his personality and the state of his digestion.

So, too, the family may be affected by the artificial nature of the experimental situation. Family members must realize at some level that their inclusion in the experiment reflects the researcher's belief that they are indeed implicated in the identified patient's disorder. Understandably, they might feel confused, frightened, or resentful and such powerful emotions are bound to affect their interactions with each other. If the family has volunteered to participate in the experiment, say, as a non-schizophrenic control, one must suspect a cooperative bias. "Interviews with non-schizophrenic families tend to indicate they are either reasonably amiable with each other or rather desperate, but at any rate they are doubtfully a random sample " (Haley, 1969-b, p. 270).

Haley (1969-b) attempted a family experiment which aimed at controlling some of these experimental variables. He acknowledged that his sample was biased and that any experiment concerning schizophrenia had a shaky theoretical base. He couched his experimental hypothesis concerning the schizophrenic's difficulty with coalitions in behaviorally-descriptive language. In order to negate observer limitations and bias, the presence or absence of coalitions among family members was recorded by machine. Once the numerical results were in however, it was the task of the human investigators to interpret them. In the end, family investigations boil down to people studying people with all the insights and blindness which that process implies.

Among the several methods used to investigate family interactions are questionnaires and a variety of interviewing techniques specifically designed to reveal interactions which the researcher considers dysfunctional (Watzlawick & Weakland, 1977). Riskin (1969) argues for the use of longitudinal, predictive studies. If there are, indeed, distinguishing characteristics of the interactions of, say, schizophrenic families, it should be possible to predict the eventual development of schizophrenic symptoms within such a family. Selvini-Palazzoli (1978) stoutly defends the family analysis which occurs naturally during therapy, maintaining that the large and varied sample of family interactions should result in a more accurate analysis. Despite the advantages of these latter research methods, they are undeniably time-consuming and costly.

Another tool for family analysis (the one used in this study) is the Family Task initially developed by the Family Research Unit of the Wiltwyck School for Boys. The Task was designed as a measuring device of broad scope for lower economic class families experiencing numerous behavior problems appearing to centre around aggression control, guidance, and nurturance. The Family Task, as reported by Minuchin, Montalvo, Guerney, Jr., Rosman, and Schumer (1967) was intended to reveal structural and dynamic differences between control and delinquent families. "The concrete 'doing' of a task which does not involve a formal testing procedure (especially of the 'paper and pencil' variety), and in which the participants can become completely submerged, has advantages for our population which have already been stressed" (p. 299).

In the Family Task, family members were seated in a semicircle surrounding a table facing a one-way mirror. The Task instructions were tape recorded rather than written because of the generally low reading abilities of family members. The experimenter was not in the room with the family during the administration of the Task. "It was felt that permitting the family to perform the task without the intrusive presence of a stranger would encourage a freer, more natural interaction" (Elbert, Rosman, Minuchin, & Guerney, Jr. 1964, p. 890). This viewpoint echoes that of Haley (1969-c): "The focus of a family study should be on the total family and on the interaction of parents and children with each other rather than on the interaction of family members with interviewers or testers" (p. 174).

The Task (see Appendix 2 for the protocol), which took approximately 45 minutes to complete, consisted of five discussion questions and the duplication of a building model. The final two segments of the Task required the family to choose a small gift and to share refreshments. Each session was tape recorded. Two observers viewed the sessions from behind the one-way mirror: one observer identified and recorded the names of the various speakers while the other noted all non-verbal activity. A transcript was prepared which was then evaluated quantitatively for such variables as leadership, behavior control, and nurturance as well a qualitatively based on analysis of the actual content of the interactions. Quantitative results were given the most weight.

A revised version of the Wiltwyck Family Test was utilized by Minuchin, Rosman and Baker (1978) as a diagnostic tool in the treatment of anorexia nervosa (see Appendix 3 for the protocol). "A major task for the experimenters was to operationalize the concepts of enmeshment, overprotectiveness, low tolerance for conflict, and rigidity so that they could be assessed in the family's transactions around carrying out the task" (p. 35). The sessions were videotaped and rated quanitatively on such behavioral characteristics as boundary violations, shifting coalitions, and communication patterns. Again the instructions were tape recorded and the examiner was absent from the room. The Task was intended to differentiate anorectic families from the families of asthmatics and diabetics, on the one hand, and from delinquent and control families, on the other. Minuchin et al. (1978) were satisfied that the Task did, reliably and significantly, distinguish anorectic families on the basis of parent-child subsystem boundary violations, conflict avoidance, rigidity of interactions, and skewed conversational patterns (the filtering of all communication through one family member).

An abbreviated and revised version of the Family Task was the method chosen in this study for investigating the interactions which occur in the families of suicidal adolescents. There were several reasons for choosing the Family Task:

1. It allows for the interplay of family dynamics without the intrusion of the examiner;
2. Its purpose is disguised in that no reference is made to the particular family pathology under study. This makes the Task suitable for use with both non-psychiatric

families and with defensive, highly-stressed families, such as the suicidal, who may be receiving counseling elsewhere;

3. The participating families would likely find the Task enjoyable and might become more aware of their interactional patterns after viewing themselves on videotape;
4. The Task provides a structured method of analysis consistent for all psychiatric or non-psychiatric families;
5. The resulting videotapes could be analyzed in a variety of ways by several raters to gain a broader perspective, and
6. The Task has been used to investigate the interactions occurring in anorectic families.

Part 2: The Interactionist Approach As Used in this Family Study

Subjects. Four volunteer families, two suicidal (identified as Family 3 and Family 4) and two non-suicidal (identified as Family 1 and Family 2), participated in this study.

The basic criterion for the selection of the suicidal families was that there must have been an attempted or completed suicide by an adolescent family member. This was an arbitrary decision made in response to the lack of a generally-accepted definition of either suicide or a suicidal family.

In addition to this basic criterion, it was initially intended that the suicidal families being studied would consist of two parents, an adolescent suicide attempter, and at least one other child. Such a family composition would have provided the opportunity to investigate the widest range of family interactions. A recent attempted suicide would have lessened the probability that pre-suicidal interactional patterns had been altered as a result of psychotherapy or the passage of time.

Obtaining volunteer suicidal families for this study proved to be very difficult. There is an undeniable stigma in our society against any family which has been touched by suicide. An adolescent's attempted or completed suicide is generally accepted as irrefutable evidence of his parents' inadequacy. It is not surprising that these families are unwilling to expose themselves to further imagined humiliation even in the interests of science. Neither participating suicidal family met all the criteria for a subject family although both satisfied the basic criterion in that they contained an adolescent family member who had attempted or completed suicide.

It was the intention in this study that the suicidal and non-suicidal family participants be matched as closely as possible in family composition i.e. that the non-suicidal subject families would also consist of both parents, an adolescent, and at least one other child. The basic criterion was one commonly adopted in interactionist family studies: that the "normal" or "control" families (labeled only as "non-suicidal" in this study) should not have received psychiatric treatment. All of these criteria were met by both non-suicidal subject families. Because Family 3 was receiving counselling, only brief, background information was collected on the participating families.

Family 1 consisted of the mother, father, daughter (age 17) and son (age 14). Another son (age 19) lives away from home. The father is a policeman. The mother is employed outside the home as a teacher. The son is in grade nine and the daughter is in grade 12. The family has lived at the same address in Edmonton for 23 years. The parents have been married for 25 years. No family member has received psychiatric treatment.

Family 2 consisted of the mother, father, one daughter (age 15) and a second daughter (age 7). A third daughter (age 20) lives away from home. The father is a policeman. The mother is not employed outside the home. The 15-year-old daughter is in grade 10; the seven-year-old daughter is in grade one. The family has lived at the same address in Edmonton for 20 years. The parents have been married for 23 years. No member of the family has received psychiatric treatment.

Family 3 consisted of the mother and a daughter (age 15). The family counselor, who could provide only sketchy background information, specifically requested that the family not be questioned further. One son is an adult living away from home. Another son committed suicide some years ago. The daughter and her mother are presently receiving counselling because the daughter has run away from home and has threatened suicide. The parents are in the midst of a bitter and protracted divorce. The father no longer lives at home and did not participate in this study. The mother is employed outside the home as a housecleaner and fulfills caretaking duties in the apartment in which the family has lived for 15 years. The daughter is in grade 10.

Family 4 consisted of the mother, father, twin daughters (age 15) and another daughter (age 17). One son committed suicide three years ago when he was 17. Two other sons, both in their twenties, live away from home. The father is a businessman. The mother is employed outside the home in a managerial position. The twin girls are in grade 10. The 17-year-old is in grade 11. The parents have been married for 30 years and have lived in Edmonton most of that time. The family received counseling after their son's suicide.

Procedure. The Family Task, according to Minuchin and his associates, requires at least 45 minutes for a family to complete. It was felt that a possible four hours of videotape to analyze imposed too heavy a burden on the raters in this study. Since an interactionist believes that family members interact with one another in a limited number of stylized ways, even a small sampling of behavior should reveal significant patterns.

The four discussion questions chosen (two basic and two alternates) were abbreviated and revised versions of questions contained in both the Wiltwyck Family Task and the Task used to study anorectic families (see Appendix 5 for the Family Task protocol). An alternate for each of the two basic questions was provided to allow for human and mechanical error. The questions were typed rather than tape recorded so that the family could refer to them during their discussion. An attempt was made to keep the questions brief and specific so that they would be within the reading comprehension of all family members.

Each family was informed of the purpose of the study and the procedure to be followed. The written consent of each family member was obtained (see Appendix 4 for the Consent). The family members seated themselves around a table facing a one-way glass. On the table were two sheets of paper each containing a discussion question. The sessions were observed and videotaped by the author. Each family viewed its own videotape upon completion of the Task. No analysis or comment whatsoever concerning the videotape was made to any of the participating families.

The four videotapes, which averaged 10 minutes in length, were reviewed by three raters. Raters A and B were certified psychologists enrolled in the doctoral programme in Educational Psychology at the University of Alberta. Both were knowledgeable in the interactionist approach and had experience in observing family interactions. Rater C was the author.

Independent raters were included in this study in order that their ideas about the interactions observed in each subject family could provide a more complete and credible analysis. In fact, it was later learned that Rater A had some prior knowledge of Family 4 and was, therefore, not totally independent. While both raters A and B were knowledgeable and experienced in the interactionist approach, it was anticipated that they would add new dimensions to the study through observations reflecting their own philosophical orientations. Agreement among the three raters on any interpretation of family interaction would increase the credibility of any resulting conclusions.

Raters A and B were asked to review the videotapes, analyzing the family interactions as they would if confronted by these same subject families in a therapeutic setting. A mental health professional, charged with the responsibility of assessing a possibly suicidal family, would not necessarily use a checklist prepared by someone else. He would assess such a family on the basis of what he had learned and experienced as well as what he privately believed about family interaction. It was anticipated, that in instructing raters A and B to so broadly interpret the videotaped family interactions, criteria of other orientations, as well as that of the interactionist, would be applied.

Rater C studied the family interactions in the light of her conceptual model of the nature of the suicidal family from an interactionist perspective.

Chapter 5: Results

> Our problem in experimenting with the family is not to show whether with their particular network they have more or less difficulty with a task, but to show what their particular network *is*.
>
> Jay Haley

I interviewed raters A and B after each had seen and studied the four videotapes. My interest was in gaining a clear understanding of their observations regarding the interactional patterns present in the subject families. In reporting the results, I have attempted to capture the flavour of each rater's style of expression.

Rater A: This rater evaluated each subject family on three criteria: their degree of emotional bonding, the strength of their parental coalition, and their problem-solving skills. She defined "emotional bonding" as the ability of family members to show their love for one another, trusting fully that their affection was returned. Both Family 1 and Family 2 received high marks for their warmth and "optimistic mutual regard" although the tone of Family 2's interactions was less humourous, slightly more detached than those of Family 1. Family 3 impressed this rater as coldly cynical, full of "oppositional distrust". She interpreted the mother's frequent sighs and hand movements as indications of tension and despair. She was impressed by the lack of friendly humour or even eye contact in this family which she categorized as disengaged. While Family 4 initially struck the rater as warm and loving, she quickly sensed that their affection was polite rather than genuine - a "pseudo-caring".

In evaluating the parents' cohesiveness, Rater A was focusing on the power structure within the family. Again, both Family 1 and Family 2 received a high rating for their style of respectful negotiation. The children's views were regarded thoughtfully but they were not allowed to dominate the discussion. The parental coalition was strong, with an even balance of power, in both families, although the father in Family 2 was slightly more dominant, the mother was rather more conciliatory. These even slight variations reinforced Rater A's belief that a wide variety of transactional styles can be encompassed with the category of workable families. In Family 3, the rater inferred that the mother's sense of helplessness and hopelessness might be attributed in part to the lack of a husband-wife coalition and such "outside forces" as job pressures or an estranged family. The result was "mother-overload". Once again the seemingly strong parental coalition in Family 4 impressed Rater A as false. She viewed the father a "pseudo-leader" when, in fact, the mother quietly dominated the family.

The criterion of problem-solving skills was intended by Rater A to determine the family's ability to deal with conflict constructively. She credited the good problem-solving skills of Family 1 and Family 2 to their belief in their ability to negotiate effectively together. Both families accepted the necessity of compromise. Each member freely expressed his thoughts and feelings and his uniqueness was accepted, even encouraged. There was no evidence of scapegoating (those who insisted on labeling themselves were immediately challenged) and no cross-generational coalitions. Rater A attributed the low rating she gave Family 3 on their problem-solving skills to their lack of confident commitment, as shown by the disheartened tone of their conversation, to finding a workable solution to their problems. Rather the mother and daughter wasted their energies distrusting and blaming each other. The mother seemed thoroughly worn-out; a defeated martyr half-heartedly attempting to impose her solutions on an indifferent and uncooperative child. Rater A categorized Family 4 as conflict-avoiders. Feelings were often poorly expressed, but even when stated clearly, such as one daughter's resentment of her household duties, they were ignored rather than dealt with. The father frequently changed the subject as a method of avoiding conflict; the mother relied on her mind-reading skills or alluded vaguely to matters she would discuss at a later time, i.e. after the videotaping.

Rater B: This rater was more affected by the structure of each family; the presence or absence of coalitions, and the strength of sub-system boundaries. Adopting Minuchin's concept of a "functional family" as one with a strong parental coalition, clear parent-child subsystem boundaries, and flexible interactional patterns, he rated Family 1 the most functional of the four subject families. The parents acted as parents, alternating the leadership and siding freely with and against each other. The family received high marks for problem-solving skills. Members expressed their feelings clearly and openly and differences in opinion were accepted and even encouraged. Rater B considered the most striking feature of this family to be its good-humoured participation in the Task. The family members leaned forward indicating their intention to work together to solve problems in a way which would be acceptable to all.

In Family 2, Rater B considered the parent-child boundaries rigid but the parent coalition weak. He viewed the father as cold and distant, interpreting the father's folded arms and tendency to turn his head away from the camera, as a sign of his disgust with the Task in particular and, possibly, his family in general. When the father did speak, it was only to reprimand or disagree and his tone was unfailingly critical and negative. The mother impressed Rater B as a timid, submissive, anxious woman, fearful of displeasing her husband, and intent on detouring any threatened conflict. In Rater B's opinion, this was a family which hated problems yet saw them everywhere. The Task was simply another problem demanding to be solved. Such a family requires a scapegoat and when the younger daughter volunteered for the role (by proposing herself as "the biggest trouble-maker" etc.), no one tried very hard to dissuade her.

The rigidity of the role playing in Family 3 especially impressed Rater B. The mother was relentless in her prosecution of the daughter who adopted the stance of a submissive withdrawer. Again and again, the mother attacked, accusing, threatening, and reprimanding the girl. There was no eye contact, no warmth, no humour in the family, not even a conviction that the two of them could talk together. It seemed to be the daughter's task to propose solutions which the mother automatically rejected in favour of her own.

In Family 4, Rater B was puzzled by the awkward seating arrangement. The father and the three daughters sat together on the couch which made conversation and eye contact among them very difficult. The mother sat to one side in her own chair. The Rater concluded that the parents marked the outside boundaries of the family unit leaving the daughter, who was seated on her father's left, on the outside. This positioning supported Rater B's conclusions, from observing the family interaction, that the daughter was indeed peripheral to the family. Rater B viewed the mother as the only relaxed family member. She seemed prepared to take charge and to solve the Task problems on her own. Behind the father's attempts at humour, Rater B sensed a fear of exposure. He hurried through the Task, over the objections of his wife and daughters, as if he were more intent on preventing embarassing disclosures than on effective problem-solving.

Rater C: This rater kept in mind her conceptual model of the suicidal family, in her analysis of each subject family. She was impressed by the atmosphere of good-natured fun which permeated Family 1's session; the joy seemed genuine. The parents sat on the outside edge of the children so that all family members leaned forward toward each other, including everyone in their conversation, laughter, and eye contact. No family member was scapegoated orcontact. No family member was scapegoated or ignored. The father was very much a part of the family, actively involving himself in the decision making. Both parents alternated quickly and easily between supplying leadership and nurturance. Everyone was encouraged to express his opinion and individual eccentricities were accepted with good humour. This family demonstrated a relaxed, flexible approach to problem-solving. Interruptions were tolerated, especially those from the younger child. The necessity for fairness and compromise was accepted by all.

Rater C considered the structure of Family 2 more traditional, less egalitarian than that of Family 1. The father assumed the pose of benign dictator, a quite common stance, in her opinion, for a father in a female-dominated family. His role was that of the harassed head of the house, beset by three sweet but scatterbrained females. His folded arms and far-away stare signaled an indifference which Rater C considered only feigned since actually, the father took an active role in the decision-making, generally allowing the women a free hand but stepping in occasionally to introduce a little fatherly reasonableness. The mother's voluntary assumption of the one-down position was the secret of her leadership: she was willing to pretend that the father was the head of the house and he was satisfied with the pretense of authority. The mother in this family was powerful but not domineering. Her soft tone of voice, her physical caresses, her evident concern for the feelings and wishes of her husband and children indicated her to be very nurturing woman. This was a somewhat traditional family in that the parents seemed in agreement that the father would satisfy the material needs of the members while the mother focused on their emotional needs. The parent-child subsystem boundaries were clear and strong; the coalitions flexible. The general tone of the session was cheerful and involved.

In Rater C's opinion, the atmosphere in Family 3 contrasted dramatically with that in either of the first two families; it was oppressive and utterly joyless. The mother and daughter were captives in a deadly power struggle. Observing the mother's monotonous, steam-roller attack of criticism and complaint, Rater C began to imagine that the mother was steadily increasing in size as the daughter was fading away. There was no true interaction between the two of them. The mother seemed to be repeating lines from a prepared and well-rehearsed script; the daughter was quietly defiant. Neither one was prepared to negotiate fairly because neither seemed to believe, probably as a result of past futile attempts, that they could reason together. The mother impressed Rater C as a controlling, demanding woman who supplied little nurturance. However, Rater C believed that the deadened, monotonous quality of the mother's speech indicated her overwhelming feeling of hopelessness. The mother was a frightened, lonely, and angry woman who saw herself as a helpless victim of life. The message the mother reiterated to her daughter was that the daughter (by being two minutes late!) had put her in a "difficult position", had put her "in danger" where she could have been injured. The mother's most revealing and devastating comment was her plea that the daughter promise to try to be different. While both Family 1 and Family 2 frequently rejected messages, this family indulged in disconfirmations. Rater C suspected a veiled threat in the daughter's later remark that every girl needs a vacation and the mother's unhappy query: who needs the vacation?

Although Family 4 initially appeared warm and happy, Rater C sensed a falseness which led her to conclude that their closeness was pretended. They were in effect, play-acting their private definition of a "normal" family. The awkward seating arrangement chosen by the family members isolated the mother physically, as perhaps she was isolated emotionally, from the rest of the family. Although the father sat with his daughters, Rater C considered that his presence was intended more as a control than a comfort. Despite the father's obvious joviality, one sensed an uneasiness, a desire to finish the Task quickly before any family secrets were revealed. When the expression of feelings was demanded, some very strong ones were produced but never explored. Intense emotions of anger and sorrow hung in the air ever so briefly until the father could distract the family's attention and thus avoid confrontation by changing the subject, making a little joke, or concluding the discussion. His message seemed to be: "keep it light!" Mother, too, discouraged open discussion by making such definitive statements as "I don't think you have too many duties around the house" and quickly joining the father in his attempt to talk of other matters. Rater C sensed that the daughter on her father's left was indeed partially excluded from the family. The anger she directed at her mother was the one genuine emotion displayed during the session and it was largely ignored. The father's attempts to include the peripheral daughter in the Game of Normal Family were only partially successful.

Chapter 6: Discussion

> The crucial differences between
> families would seem to reside in the
> sorts of transactions which take place
> between family members; the study of
> differences becomes a classification of
> communication patterns in the family.
>
> Jay Haley

Agreement in the Ratings

All three raters were in agreement in their analysis of Family 1 and Family 3. These two families appeared almost diametrically opposed. Family 1 was a happy family with a strong parental coalition, a clear style of communication, mutual love and respect and good problem-solving skills. They were judged free of perverse triangles, disconfirmations, and the evil effects of being either enmeshed or disengaged. Family 3, on the other hand, partially fit the conceptual model of the suicidal family presented in this thesis. The mother was so intent on maintaining her control that she was virtually oblivious to her daughter's feelings and desires. Conflict was neither avoided nor resolved. Above all, the family interactions were utterly joyless. The presence of the husband and one other child would have made it possible to ascertain the strength of the parental coalition, the presence or absence of any parent-child coalitions, and whether the daughter was indeed scape-goated in this family. As it was, no conclusions could be drawn regarding any of these characteristics of suicidal families.

Raters A and C were very much in agreement in their analyses of Family 2 and Family 4. They regarded Family 2 as exhibiting a different interactional style from that of Family 1 but one still within Minuchin's concept of a functional family. Both raters concluded that the apparent emotional closeness of Family 4 was false. However, both Raters A and C did know that Family 4 had experienced a suicide and that knowledge may have sensitized them in that regard. The interactional style of Family 4 resembled that of the conceptual model of the suicidal family in several ways. Any natural joyfulness the family might have experienced was consumed by their desire to appear normal and therefore blameless. The family was clearly afraid of strong emotion and conflict.

Rater B's evaluations of Family 2 and Family 4 differ from those of the other two raters more in degree than in kind. He saw the same qualities of interaction in Family 2 as did raters A and C, but he considered those characteristics more dysfunctional than functional. In evaluating Family 4, Rater B noted the uneasiness and pretense but these qualities of the interactions did not have the same impact on him as they did on the other two raters.

No generalizations, regarding the characteristics of suicidal families, can be justified by such a limited study as this one. Minuchin and his associates believed that the Task was a benign method of studying families under stress. While possibly less threatening than a therapeutic interview, the Task undoubtedly creates stresses of its own and it is difficult to measure the effect of an artificial, experimental situation. However, this study does suggest that much insight into a family's interactions can be gained in only 10 minutes observation. It also suggests that the characteristics of interaction will be sufficiently pronounced to capture the attention of several observers of divergent experience.

The interactions of the two suicidal families in this study provided at least a limited support for this thesis' conceptual model of a suicidal family. There was a sense of joylessness or at least, pretended harmony recognized by all three raters in the suicidal subject families. Conflict was avoided either by discouraging free expression as in Family 3 or by ignoring it as in Family 4. The raters agreed in their assessment of the mother in Family 3 as domineering. There was at least an element of unity in their recognition that the father in Family 4 was less involved than, say, the father in Family 1. Perhaps a more complete sampling of behavior would have persuaded Rater B that the father in family 4 was indeed more peripheral than he pretended to be.

Disqualification in the Ratings

Apart from the one example of disconfirmation in Family 3's communications noted by Rater C, there was little analysis made of the rejection or confirmation of communications within each family. This omission is undoubtedly due to the fact that without a transcript, it is virtually impossible to unravel the complexities of speech.

While all three raters attempted to respond to the non-verbal behaviors in the subject families, it is again suggested that a transcript complete with notations of all body and facial movements would greatly improve the accuracy of the interactional analysis.

Limitations of This Study

The two suicidal families in this study were less than ideal subjects. They constituted neither a random nor even a representative sample of suicidal families. One wonders if different results would have been obtained using families with adolescents who had exhibited a greater variety of suicidal behaviors including obvious suicide attempts as well as suspicious accidents.

All of the raters were troubled by the absence of some family members. The undoubted value of including the husband and another child in the videotaped interactions of Family 3 has already been discussed. Although three daughters participated in Family 4's Task, Raters A and C speculated that the presence of even one son would have indicated whether the father treated his sons differently i.e. more critically than he treated his daughters.

Of course, a non-suicidal family is not synonomous with a "normal" family. The label "non-suicidal" was chosen to avoid the problem that "normal" families have neither been defined nor studied by interactionists. However, the non-suicidal families, which participated in this study, may have been dysfunctional according to some criterion not measured by the Family Task or, at least, atypical. One must raise the issue of the motivation of volunteer families but there is as yet, no generally-accepted desirable investigational motivation. Despite these concerns, it is the conclusion in this thesis that the Family Task, even an abbreviated and revised version, has proven useful and worthy of future study as a measure for analyzing the interactions in suicidal families.

Exploration of the Conceptual Model

In Chapter 3, I conceptualized certain characteristics of the suicidal family. Some of those characteristics, such as the presence of more rejection and disconfirmation that acceptance of communication, are truly interactionist criteria. Other qualities, such as a sense of joylessness, could not be expressed in interactionist terms.

In developing the conceptual model, it was anticipated that some suicidal families would appear more obviously dysfunctional (as defined by Minuchin) than others. In this study, all three raters considered the communication patterns of Family 3 to be pathological. However, Family 4, the other suicidal subject family, was viewed by rater B as no more dysfunctional than Family 2, a non-suicidal family.

The conceptual model of the suicidal family indicated that maternal ambiguity or rejection would be apparent in the high proportion of rejecting and disconfirming communication. Unfortunately, the lack of transcripts, specifically recording both verbal and non-verbal behavior, made evaluation on this criterion impossible.

It was predicted that the mother in the suicidal family would be coldly domineering; the father passive and peripheral. The raters agreed on such a characterization of the mother in Family 3 but not in Family 4. The father in Family 4 impressed two of the three raters as indeed peripheral but both of those raters knew that Family 4 was a suicidal family.

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THE UNIVERSITY OF ALBERTA

PRESTRESSED CONCRETE TEE BEAMS CONTAINING LARGE CIRCULAR WEB OPENINGS

by

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A THESIS
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "PRESTRESSED CONCRETE TEE BEAMS CONTAINING LARGE CIRCULAR WEB OPENINGS" submitted by Alastair K. Dunbar in partial fulfilment of the requirements for the degree of Master of Science.

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DATE October 4 / 1976

TO JANE

ABSTRACT

The research described in this thesis is the fourth such series of tests in a program initiated at the University of Alberta to study the behaviour of Prestressed Concrete tee beams containing large web openings. The experimental phase was carried out in the I. F. Morrison Structural Engineering Laboratory at the University of Alberta under the supervision of Dr. J. Warwaruk.

The present test series consisted of twelve Prestressed Concrete tee beams with large circular web openings, loaded to failure with two symmetrically placed point loads. All beams were 20 inches deep with a 20-inch flange and were prestressed with five prestressing strands of 3/8-inch diameter.

The major variables were: the amount and arrangement of shear reinforcement, the size and spacing of the web openings, and the positions of the load points.

Although further study is required to develop a rational design procedure for such beams, it was concluded that the most critical factor is the provision of adequate shear reinforcement across the minimum sections above and below the circular openings. Nominal reinforcement in the posts between holes seemed sufficient to avoid failure in those regions.

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CHAPTER I

INTRODUCTION

In building construction, the reduction in floor thickness made possible by passing building services through floor-beams, rather than under them, can cause a significant reduction in construction and maintenance costs, by reducing the total building height and volume. This is often accomplished using open-web steel joists or expanded-web steel girders. In concrete construction, the same effect can be achieved by either allowing the cutting of web openings by those involved in the installation of services which is a dangerous practise, or by designing beams containing web openings.

At the present time, however, there is not sufficient information available to allow an engineer to design such beams with any confidence in both their safety and economy. With the long-range goal of contributing to the development of design procedures, an experimental program was initiated at the University of Alberta to study the behaviour of prestressed concrete tee beams containing large web openings. The first part of the program was Sauve's study(10) of prestressed concrete tee beams containing rectangular web openings and various arrangements of longitudinal and vertical shear reinforcement. Le Blanc(3) continued with similar test beams, also varying the hole shape, the prestress force, and the slope of the shear reinforcement. Finally, Linder(4) examined in more detail the effects of these variables, introduced further variations of shear reinforcement, and also varied hole size.

The present series shifts the focus from rectangular and parallelogram shaped openings to circular ones. The variables of principal concern were arrangement of shear reinforcement and loading configuration, although the effects of varying hole size and spacing were also briefly considered.

Twelve beams were tested, the results being recorded in the form of Demec strain gauge readings, electrical resistance strain gauge readings, and deflection readings. In addition, photographs were taken of the beams at various loading stages to record cracking patterns and failure modes.

CHAPTER II

REVIEW OF PREVIOUS WORK

The use of concrete members with large web openings is much less widespread than the use of open-web steel joists and other truss-type steel structures. In order to enable concrete to provide a better alternative than it has in the past, economical and reliable design procedures must be developed. To this end a limited amount of research has been done which suggests that such an alternative may be viable, but requires further research.

2.1 Prestressed Concrete Tee Beams with Large Web Openings

Sauve(10) conducted tests in the Structural Engineering Laboratory of the University of Alberta on nine prestressed concrete tee beams with rectangular web openings. This program investigated nine 24 foot model beams tested under two point loads at various spacings. Other variables included: vertical shear reinforcement, as well as longitudinal reinforcement and supplementary lower web shear reinforcement.

Some observations and conclusions from this program were:

a) Prestressed concrete tee beams containing large web openings cannot be designed for flexure using the ACI Code's minimum shear reinforcement conditions, even though the actual ultimate shear capacity obtained could far exceed that designed for flexure.

b) Any additional shear reinforcement provided, served to increase the load carrying capacity of a beam containing large web openings by an amount ranging from 15% to 22%.

c) Additional shear reinforcement also confined failure to a location where there was an abrupt change in cross-sectional area of concrete.

d) An amount of vertical reinforcement, placed in the posts, gave these posts the capacity required to cause a localizing of the failure in the lower web, if this web had no vertical reinforcement. However, placement of a minimum amount of inclined shear reinforcement in the lower web caused the failure to be localized in the posts.

e) The addition of both post and lower web reinforcement resulted in a redistribution of stresses in the shear span such that all sections were more equally stressed in diagonal tension.

f) Considerable increase in supplementary longitudinal reinforcement did not significantly increase the shear capacity of the beams.

g) A decrease in the number of openings in the shear span increased considerably the shear capacity of the beams.

2.2 Parallelogram Shaped Openings in Prestressed Concrete Tee Beams

Le Blanc(3), in a follow-up to Sauve's work, tested ten prestressed concrete tee beams with rectangular and parallelogram shaped web openings in the Structural Engineering Laboratory at the University of Alberta. The details of the beams were similar to Sauve's, and were tested under various load arrangements. The prestress force and the amount of shear reinforcement used were two important variables, however the main concern was the effects of the parallelogram type openings in the beams, compared with the rectangular openings or no openings.

Some of his observations and conclusions were:

a) Parallelogram shaped openings accompanied by inclined shear stirrups, in prestressed concrete tee beams containing web openings, result in a beam with a higher ultimate capacity relative to rectangular shaped openings and vertical shear stirrups, when the failure is a shear failure or a combined shear and bending type of failure.

b) Since shear failures occur through the hole sections, shear reinforcement in the posts is not sufficient in itself to prevent a shear failure.

c) Lower web reinforcement in the shear span below the web openings, increases the ability of the beam to withstand more severe shear stresses, thereby increasing the possibility of flexural failure.

d) Shear reinforcement, above the hole sections in the shear spans, would probably increase the possibility of a flexural failure in cases where the loading produces severe shear stress conditions, since shear failures tend to initiate in this region.

e) The ultimate load and moment calculated using the theoretical ACI Code procedure, in the case of flexural failures, is very conservative relative to the measured ultimate load and moment obtained from these tests.

f) Deflections at flexural ultimate loads were higher for beams having web openings than for the control beam having none, due to the decrease in initial stiffness caused by the introduction of the openings.

2.3 Prestressed Tee Beams with Large Web Openings

Ragan and Warwaruk(8) tested six prestressed tee beams containing web openings. In this program, four model beams were tested in the Structural Engineering Laboratory of the University of Alberta and two full size beams were tested in the field. The design of the two full size beams was based on the results obtained from the model beams.

Some of their observations and conclusions were:

a) Cracking extended vertically downward from approximately ~~the~~ centre point of the web openings; hence it was concluded in the full size beams, to distribute the prestressing strands almost evenly across the vertical section of the lower web.

b) Severe cracking at the connection of the "post" and flange led to the provision of steel in the posts at 1.3% of the horizontal area of these posts.

c) All failures were due to inclined cracking in the lower web and always in the half span which had the least amount of web reinforcement; hence the full size beams were provided with "U" stirrups in the lower web spaced at six to twelve inches.

d) The mode of failure of all beams with openings was by the formation of mechanisms. None of the beams, neither model or full size, failed in a flexural manner.

2.4 Reinforced Concrete Tee Beams with a Web Opening

Lorentsen(5), of the Royal Institute of Technology in Stockholm, conducted analytical and experimental research on reinforced concrete girders having a single web opening. Four beams were tested under different loading conditions.

In general, his tests confirmed the behaviour pattern predicted by the elastic theory and also showed that there was a reserve of capacity available, due to the redistribution of moments between stressed sections located at the edges of the openings. Lorentsen also showed that for statically loaded structures, satisfactory structural capacity can be achieved if the sections near a hole are designed to resist the normal and bending forces. He pointed out that in simply supported beams supporting a uniformly distributed load, there are two factors which make the location of a hole near the midspan desirable:

a) The magnitude of the flange moment, and

b) The low shear force relative to normal force

The flange moment refers to the moment in the upper flange at the left end of the hole, not the contribution of flange compression to overall moment resistance at a section. Since this moment is basically the sum of the fixed end moment of the flange itself induced by the portion of the load applied above the hole and thus dependent only on hole length, and a component produced by the transverse shear at the section, it follows that the flange moment will be minimal near the centerline. Similarly, the high normal force in the flange at centerline, relative to shear force, enhances the shear capacity of the flange, while the opposite situation at the supports induces high principal tension stresses in the flange.

An important conclusion which Lorentsen made is that, in the region of a hole, the members should be overdesigned with respect to crushing of the concrete. This guards against the occurrence of a plastic condition at working loads. Such a condition is not desirable, since the moment near a hole may change sign, depending on the position of the load. He also concluded that the principles presented can be applied to cases where more than one hole exists.

2.5 Rectangular Reinforced Concrete Beams with Large Web Openings

Nasser, Acavalos and Daniel(7) of the University of Saskatchewan, tested nine rectangular beams containing web openings. They were able to verify that: large openings behave similarly to a Vierendeel panel, contraflexure points exist at the approximate midspan of the cross members, the diagonal force concentration at the corners of an opening is twice the simple shear force, and adequately reinforced large openings do not reduce the ultimate capacity of a beam, but reduce the stiffness and hence increase deflections.

2.6 Circular Openings in Webs of Continuous Beams

Somes and Corley(11) conducted tests in the Portland Cement Association Structural Development Laboratory on 19 reinforced concrete tee beams containing circular web openings. The specimens were proportioned to model the negative moment region at an interior support of a typical continuous joist and were cast with sanded lightweight-aggregate concrete. Some of their design recommendations were:

a) An opening should encroach no closer to the extreme compression fibre than the depth of the equivalent rectangular stress block "a" defined by Sec. 10.2.7(1). With this requirement satisfied, small isolated openings may be located anywhere in the web without strength reduction.

b) Large openings should have well-anchored stirrup reinforcement on either side. This reinforcement should be located as close to the opening as is consistent with the ACI standard requirements for concrete cover.

c) On each side of a large opening the area of stirrup reinforcement should be not less than the shear capacity of the joist at the location without the opening divided by the specified minimum yield strength of the stirrup steel. The shear capacity should be calculated according to Sec. 11.5(1).

d) Where multiple openings are used, the minimum horizontal dimension of the concrete between adjacent openings should be not less than 0.25 of the web depth or 4 inches, whichever is greater.

CHAPTER III

RESEARCH PROGRAM

This test series forms the fourth part of a program initiated to supply the experimental background necessary for the development of adequate design procedures for prestressed concrete tee beams containing large web openings. The first three series studied the effects of rectangular and parallelogram shaped openings on the behaviour of such beams, while this investigation introduces circular web openings.

Justification for the study of the effects of circular holes is two-fold. First, many of the building services that may be threaded through the holes are cylindrical, such as plumbing and some air-ducts, or would fit as easily through circular holes as any other shape, such as electrical conduit. Thus in practice a circular hole may be more desirable than a rectangular one. Second, intuition, supported by the results of the tests, suggests that the mode of behaviour of a beam is strongly influenced by web opening geometry. Thus a design of a beam with circular web openings based only on studies of rectangular holes would at best be a crude approximation.

The fabrication and testing of the beams of this study were carried out concurrently with those of Linder. Good co-ordination of the two test series avoided logistical problems in the laboratory, and improved the efficiency of both operations with respect to time, material, and manpower.

Twelve specimens, described in Table 3.1 and Figure 3.5, were tested, each containing circular web openings. The section used was a simple tee with an overall depth of 20 inches, as illustrated in Figures 3.1 and 3.2. The location of the centerlines of the holes was at a depth of 8-1/2 inches from the top of the flange. Unlike previous sections used by Le Blanc and Sauve, no corners were beveled, although 1-1/2 by 1-1/2 inch fillets were formed at the web-flange junctions. Longitudinal mild steel reinforcement consisted of eight #3 deformed reinforcing bars, extending through the full length of all beams. Four of these were placed at mid-depth of the flange, two just above the holes, and two in the bottom of the web. In this way the steel was proportioned to resist initial tension stresses in the flange, to increase the moment capacity of the section, and to facilitate construction and handling of the reinforcing cages. Five seven-wire prestressing strands of 3/8 inch nominal diameter were positioned at the corners and centre of a 2 inch by 2 inch square at an average depth of 16 inches.

The first beam had ten holes spaced at 16 inches on centre, a span between support centerlines of 20 feet, and two loads placed symmetrically on the beam 8 feet apart.

Subsequent beams had holes spaced at 20 inches, spans between support centerlines of 20 feet 4 inches (for beams AD-2 to AD-4), or 16 feet 4 inches (for beams AD-5 to AD-12), but with the two loads located 8 feet 4 inches apart. These proportions enabled the loads to be placed midway between holes, while maintaining constant hole spacing throughout the perforated region and shear spans of either four or six feet. The length allowed for anchorage of the strands beyond the support centerlines at each end varied from 1 foot 6-1/2 inches to 2 feet, depending on the space available in the forms. There were seven or nine holes per beam (depending on beam length) of 8 inch (beams AD-7 and AD-8) or 10 inch diameter. Thus, while the average hole area per foot of beam length was less than that of beams with rectangular or parallelogram shaped holes by from 11% to 57%, the maximum depth of web removed by a hole was 25% higher.

The arrangement of shear reinforcement was the principal variable. It consisted of full-depth open U-stirrups of #3 deformed bars, and smaller closed stirrups of #2 bars. The U-stirrups placed at 45° and 90° to the longitudinal axes of the beams were bent to the specified shape by the supplier, while those placed at 60° were produced in the laboratory by re-bending the 45° stirrups. The smaller stirrups were fabricated in the laboratory from straight #2 bars bent on a simple bending jig, and were placed at 45° above and below the holes. The lower web stirrups were anchored by means of wire ties where their ends lapped around a corner. Figures 3.3 and 3.5 show stirrup details and locations in the test beams.

The prestressing operation was carried out between two reinforced concrete abutments anchored to the load floor. The first four beams were cast singly, the second four were each cast with one of Linder's beams in tandem, while the last four were cast as two pairs in tandem. The formwork used was that designed by Linder, consisting of built-up steel forms lined with plywood treated to resist damage from fresh concrete. The openings were formed by styrofoam blocks held in place by small truncated plywood "cones" which were wedged into sockets in the blocks. These cones were attached to the form liners with wood-screws such that they could be easily relocated.

The concrete mix used was proportioned to produce a nominal strength of 5000 psi, and contained High Early Strength cement. Typically, three standard test cylinders were cast from each batch of concrete, allowed to cure under the same conditions as the beams, and were then tested for compressive strength and tensile splitting strength on the same day as the corresponding beam test. Transfer of the prestress force was accomplished after either a four or five day moist curing period. The beams and cylinders were then stored in an exposed condition in the laboratory, until being tested at ages ranging from 15 days to 36 days.

The instrumentation of the beams was of three types: electrical resistance strain gauges, Demec points, and metal scales graduated in hundredths of an inch. The strain gauges were mounted on the shear reinforcement at locations that appeared to be critical, judging from the cracking behaviour of the first beams, and on the prestressing strands at selected sections. These were carefully waterproofed with a coating of epoxy, which also served to protect them from being damaged by the aggregate during casting. Pairs of Demec points were mounted at a section near the beam centerline as shown in Figure 3.4 to determine the strain changes induced by creep and elastic shortening at transfer, especially at the level of the prestressing strands in the lower web. Strain distributions across the depth of the section were also derived as the beams were loaded. Deflection readings were obtained for each increment of load with the use of a surveying level and scales suspended from the bottom of the web at the load points and centerline.

The loading apparatus, as pictured in Figure 3.7, consisted of two hydraulic jacks mounted on a steel frame secured to the load floor, and two concrete pedestals. The jacks were controlled from an Amsler loading apparatus, such that they would exert equal loads, and were positioned to bear down on two steel plates, plastered to the top of the flange. The rounded knife-edges, which provided the point of contact between the beams and the supports, were mounted on small roller-wheeled carts that traveled on bearing plates bolted to the concrete pedestals. To provide structural stability, one of these carts was restrained by a threaded rod, while the other was free to roll as the bottom fibre of the beam elongated. This motion of the rolling support upset the symmetry of loading by allowing the centre portion of the beams to move in the same direction. To counteract this undesirable effect, the position of the fixed support could be adjusted during testing by means of the threaded rod. The underside of the web was protected from stress concentrations by the steel beam seat of Figure 3.6. To guard against the slight possibility of a beam tipping over sideways under high loads, a frame of 5 inch channels was bolted across each end of the loading frame above the test beam to restrain the flange.

TABLE 3.1

GENERAL BEAM DATA

BEAM NO.	CLEAR SPAN ft,in	SHEAR SPAN ft,in	NO. OF HOLES	HOLE SIZE in	HOLE SPACING in	AGE AT RELEASE days	AGE AT TESTING days
AD-1	20-0	6-0	10	10	16	5	27
AD-2	20-4	6-0	9	10	20	5	23
AD-3	20-4	6-0	9	10	20	5	23
AD-4	20-4	6-0	9	10	20	4	22
AD-5	16-4	4-0	7	10	20	5	34
AD-6	16-4	4-0	7	10	20	5	30
AD-7	16-4	4-0	7	8	20	5	15
AD-8	16-4	4-0	7	8	20	5	20
AD-9	16-4	4-0	7	10	20	5	29
AD-10	16-4	4-0	7	10	20	5	36
AD-11	16-4	4-0	7	10	20	4	19
AD-12	16-4	4-0	7	10	20	4	21

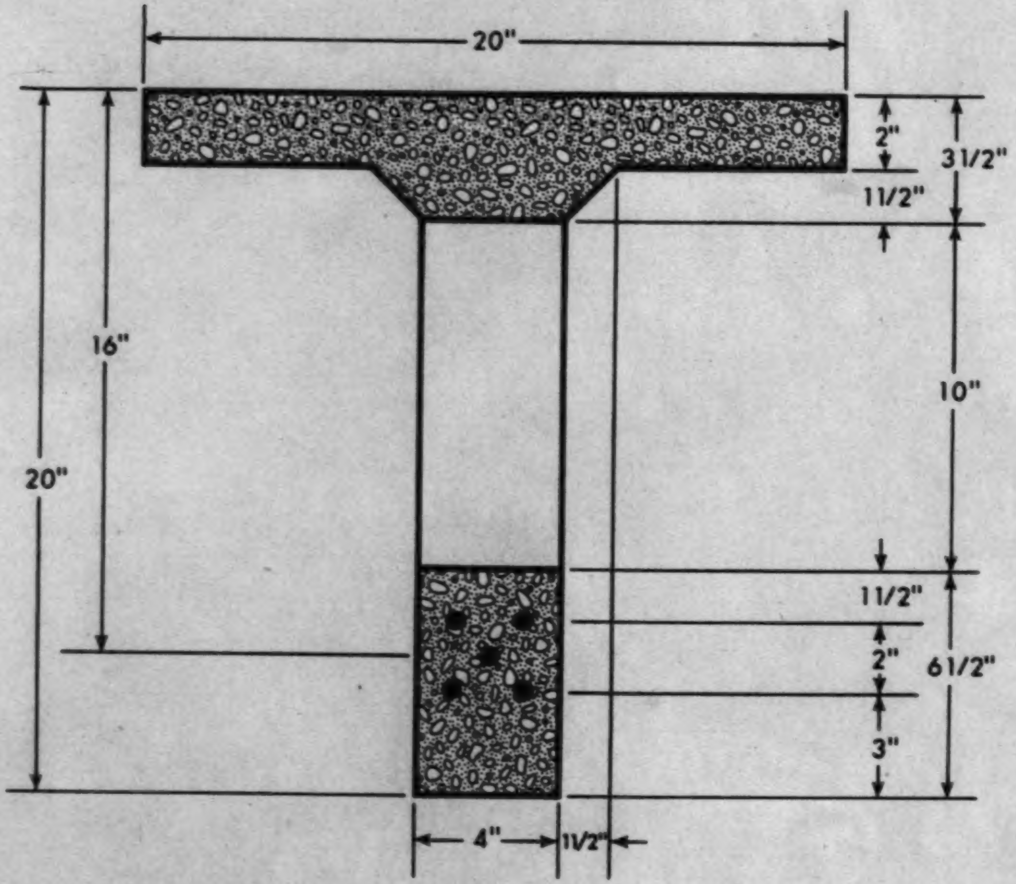

20"
2"
3 1/2"
1 1/2"
16"
10"
20"
1 1/2"
2"
6 1/2"
3"
4"
1 1/2"

FIGURE 3.1

TYPICAL CONCRETE CROSS-SECTION

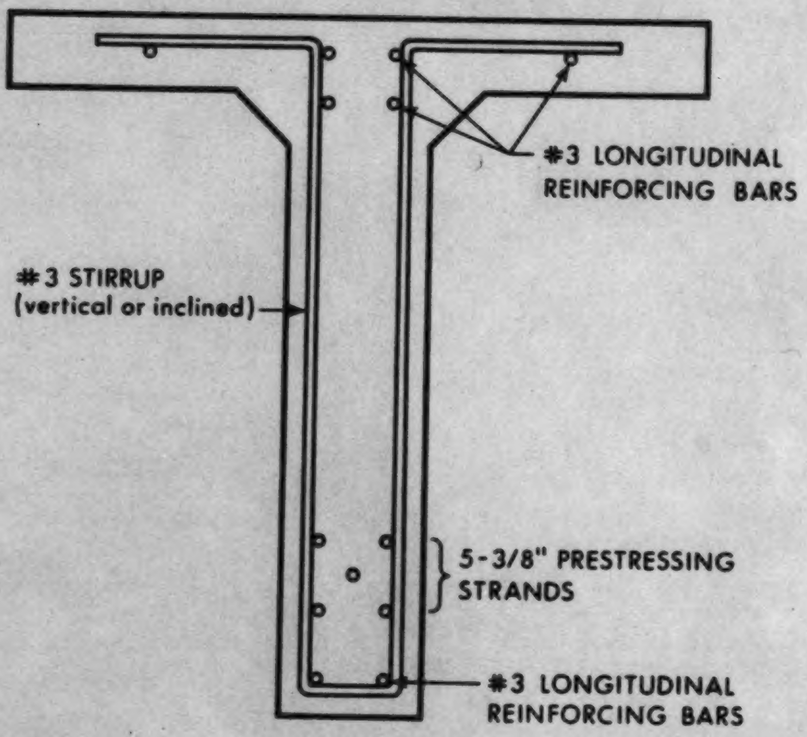
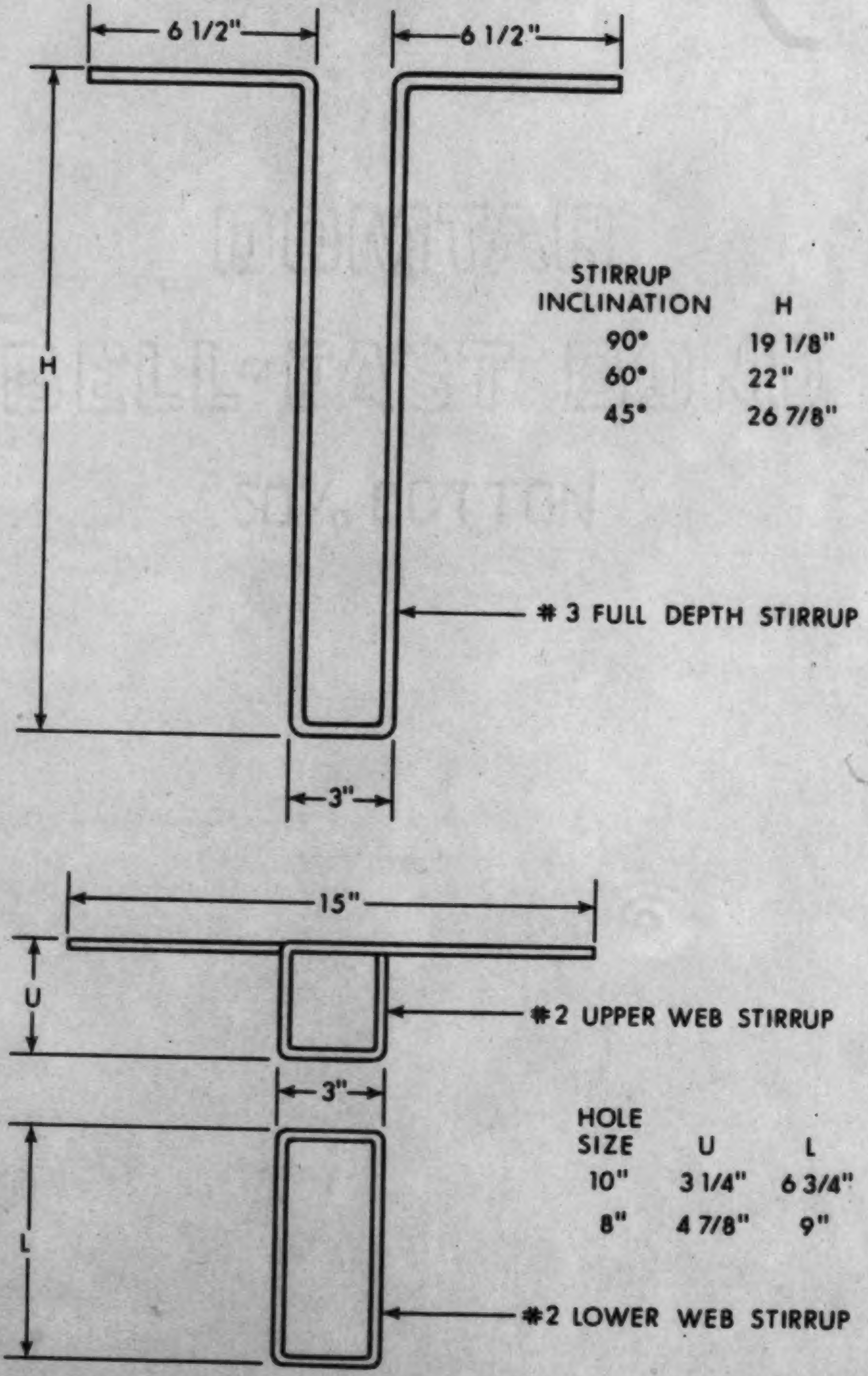

#3 LONGITUDINAL REINFORCING BARS
#3 STIRRUP (vertical or inclined)
5-3/8" PRESTRESSING STRANDS
#3 LONGITUDINAL REINFORCING BARS

FIGURE 3.2

TYPICAL REINFORCEMENT DETAILS


6 1/2"
6 1/2"
H
# 3 FULL DEPTH STIRRUP
3"
15"
U
#2 UPPER WEB STIRRUP
3"
L
#2 LOWER WEB STIRRUP

STIRRUP INCLINATION	H
90°	19 1/8"
60°	22"
45°	26 7/8"

HOLE SIZE	U	L
10"	3 1/4"	6 3/4"
8"	4 7/8"	9"

FIGURE 3.3

STIRRUP DETAILS

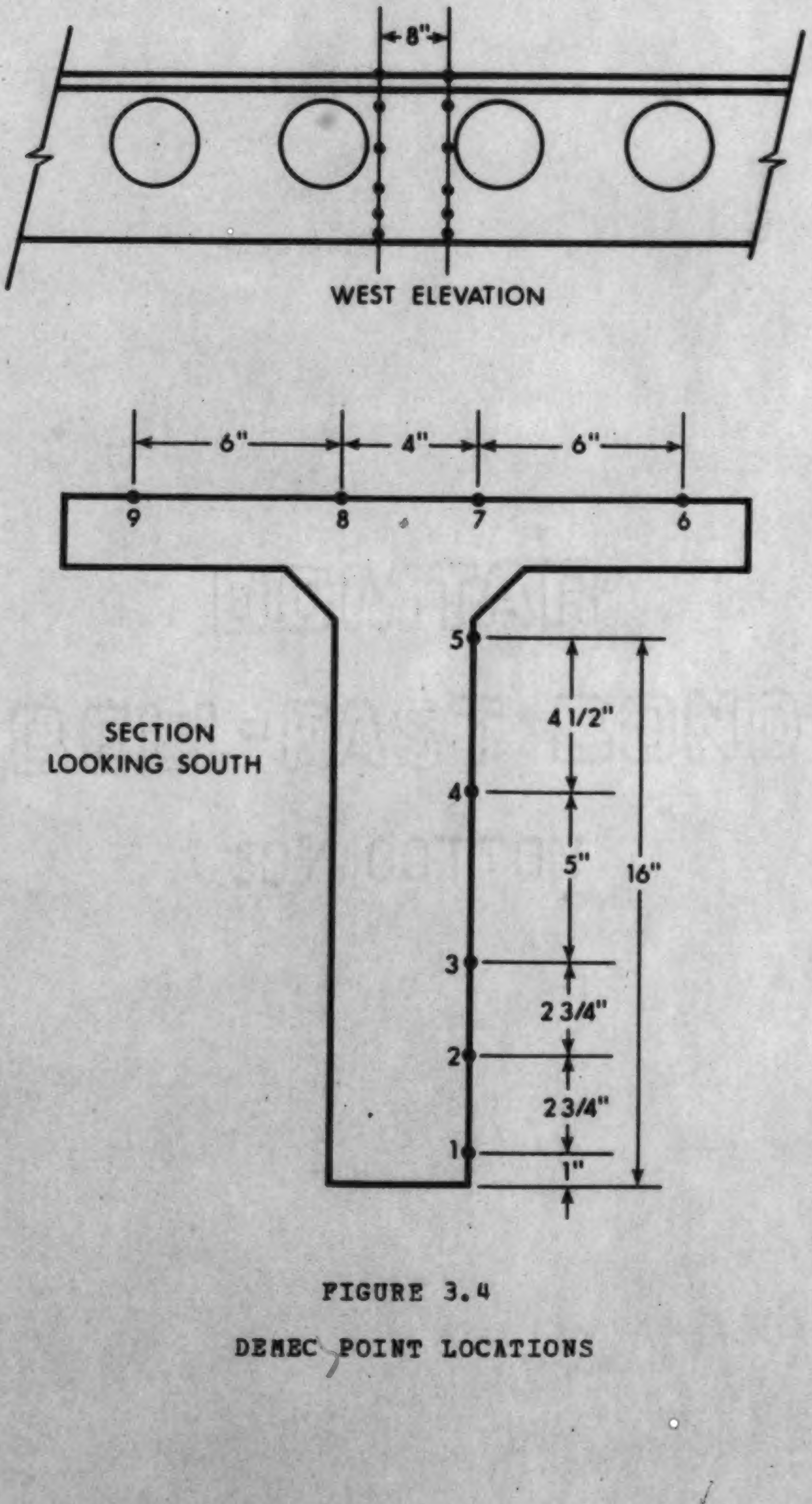

8"
WEST ELEVATION
6"
4"
6"
9
8
7
6
5
4
3
2
1
4 1/2"
5"
2 3/4"
2 3/4"
1"
16"
SECTION
LOOKING SOUTH

FIGURE 3.4

DEMEC POINT LOCATIONS

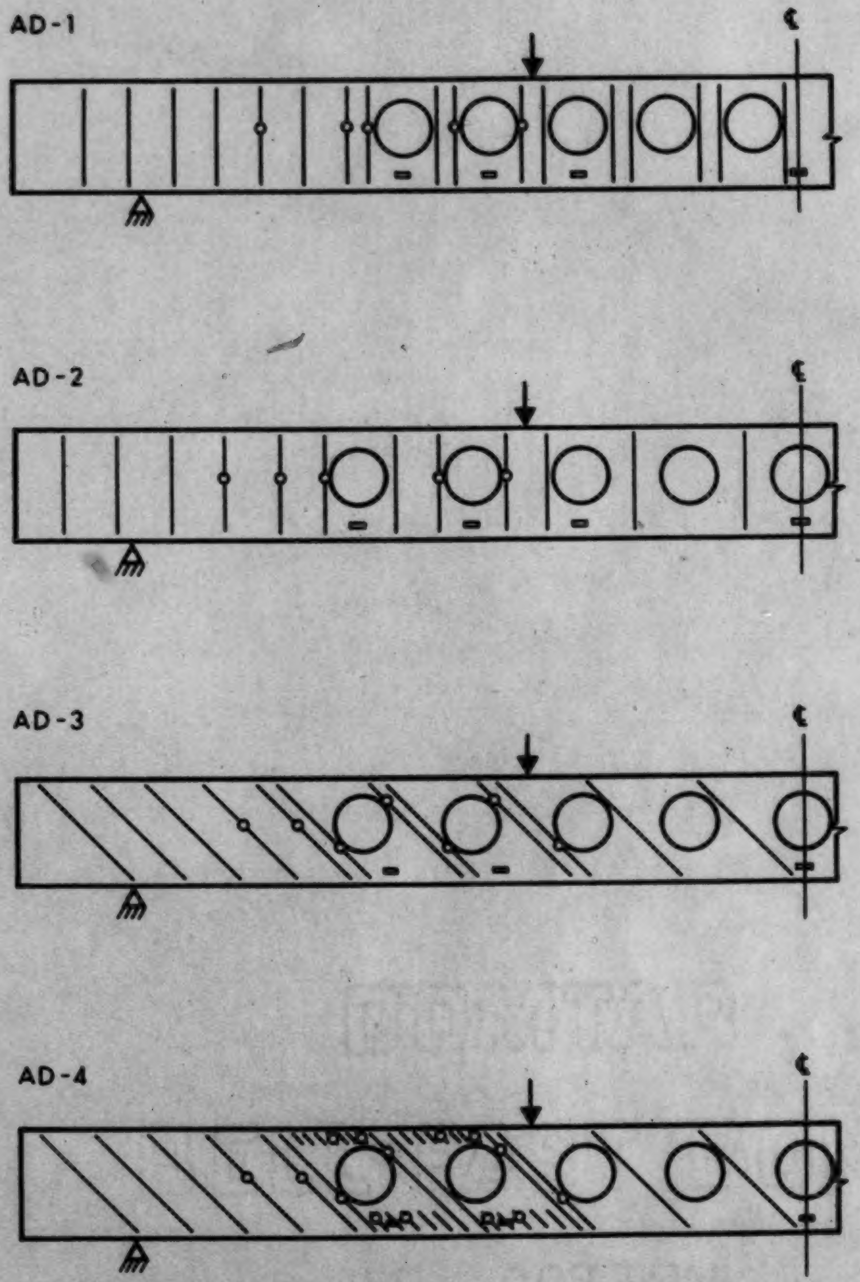

AD-1
℄
AD-2
℄
AD-3
℄
AD-4
℄
RAR
RAR

FIGURE 3.5.1

SHEAR REINFORCEMENT DETAILS CASTING GROUP ONE

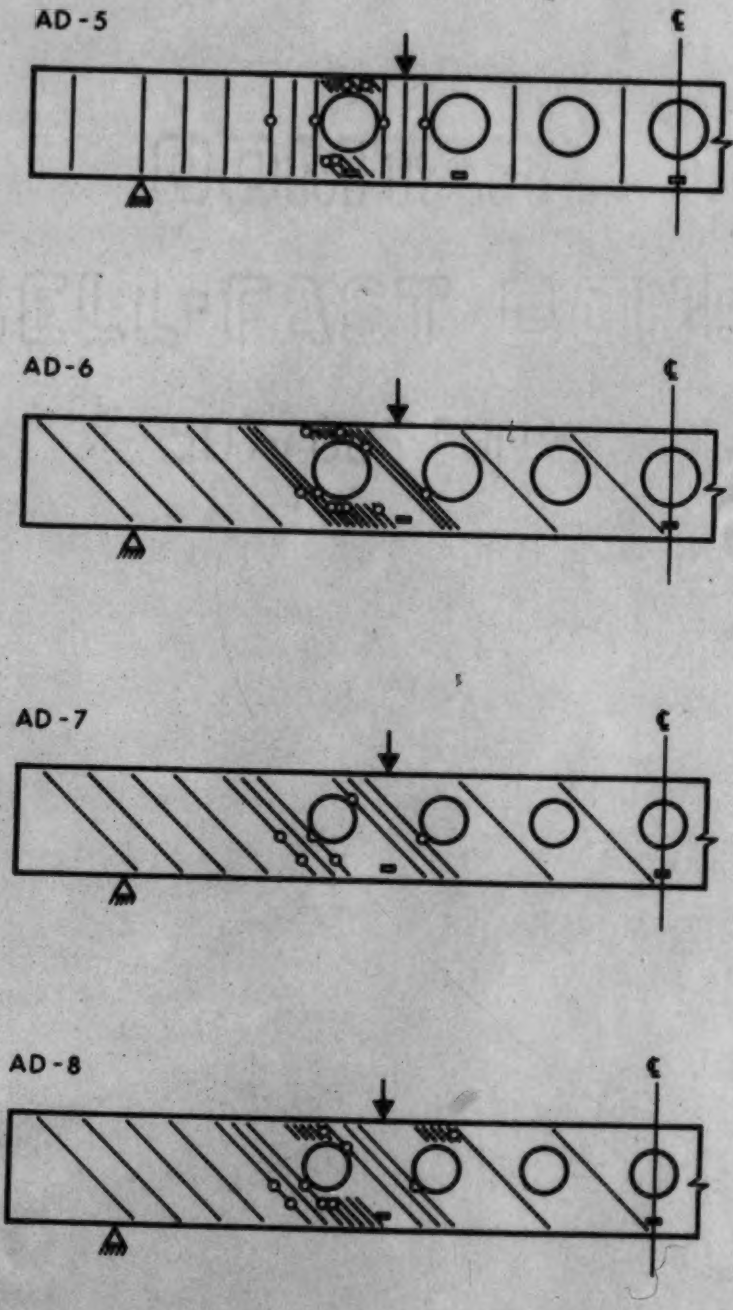

AD-5
℄
AD-6
℄
AD-7
℄
AD-8
℄

FIGURE 3.5.2

SHEAR REINFORCEMENT DETAILS CASTING GROUP TWO

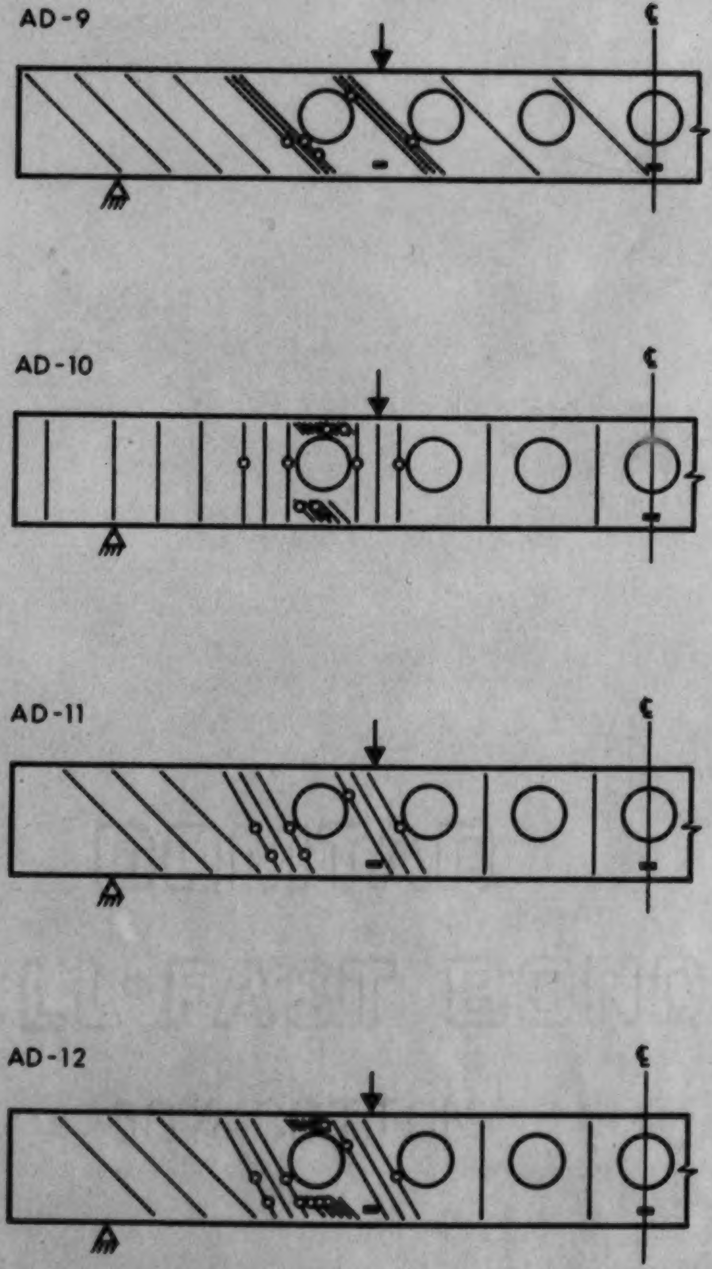

AD-9
℄
AD-10
℄
AD-11
℄
AD-12
℄

FIGURE 3.5.3

SHEAR REINFORCEMENT DETAILS CASTING GROUP THREE

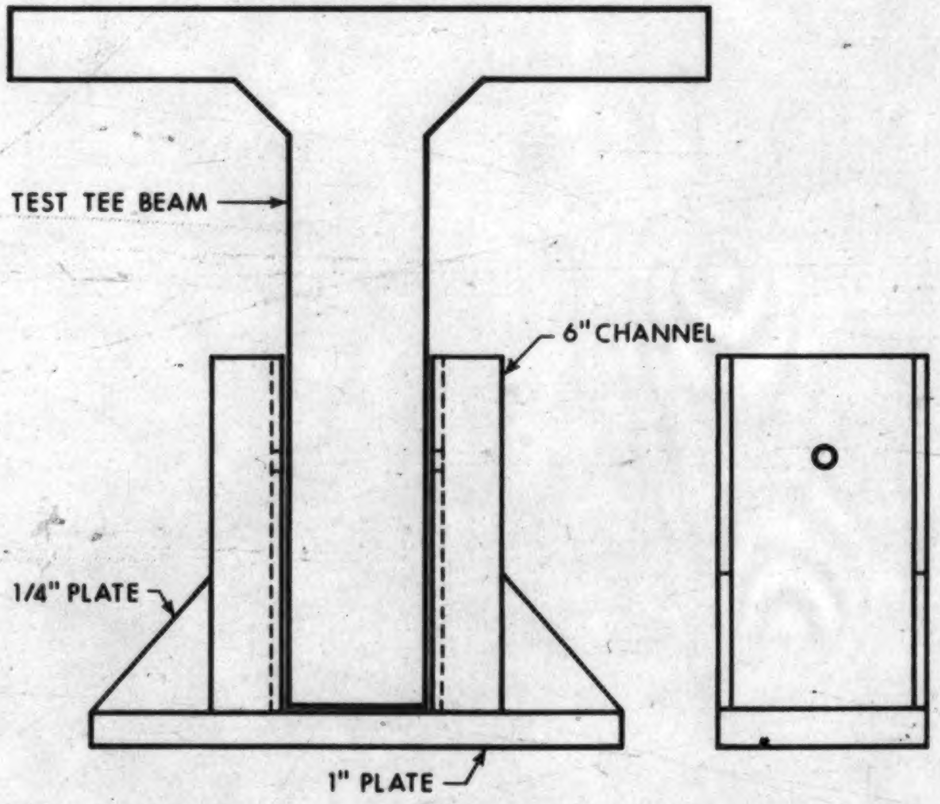
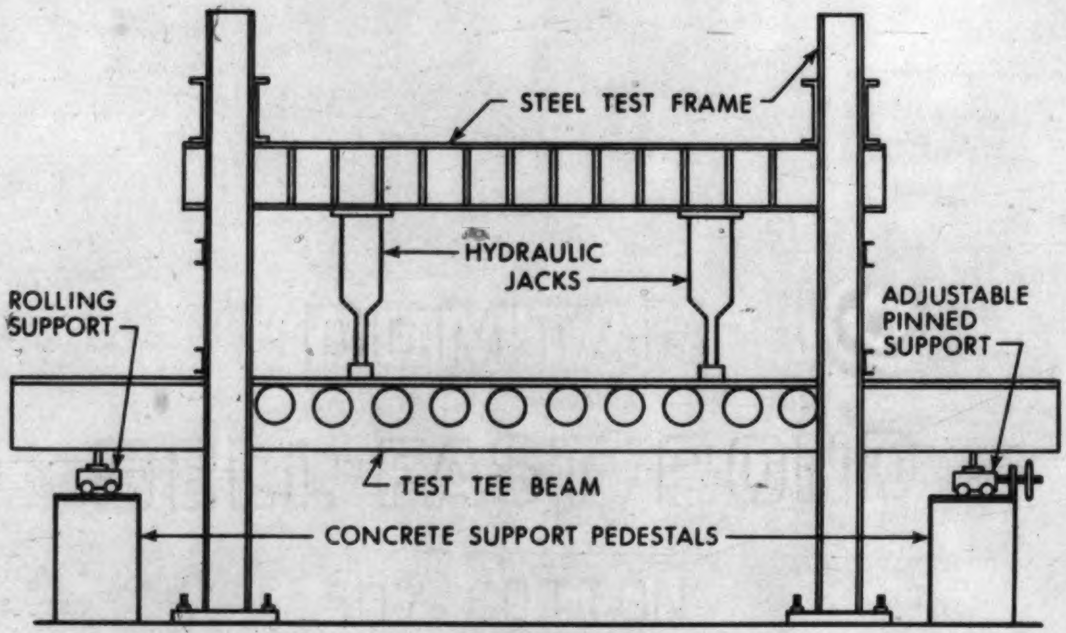
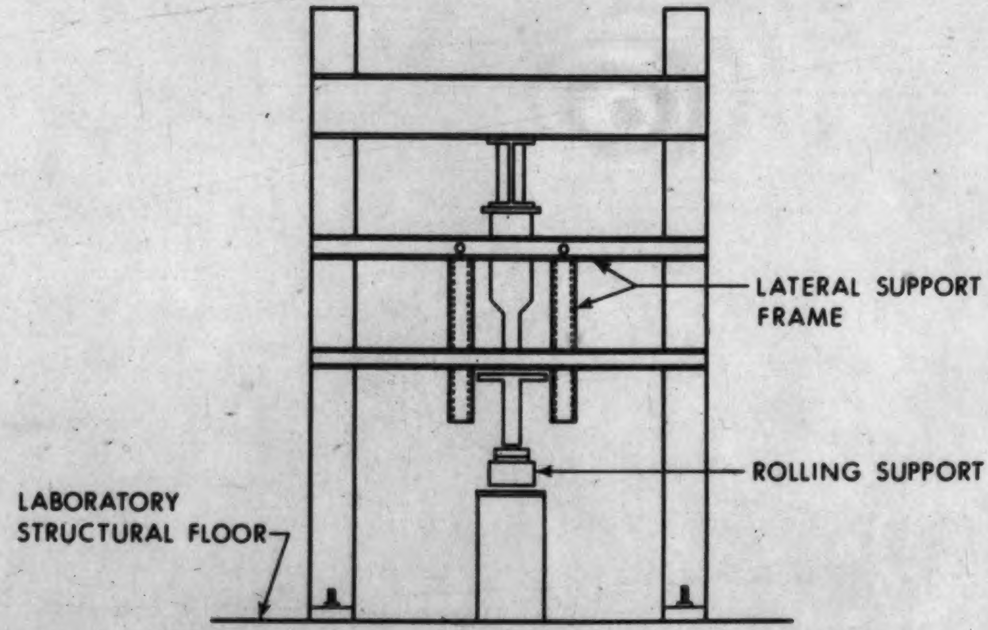

TEST TEE BEAM
6" CHANNEL
1/4" PLATE
1" PLATE

FIGURE 3.6

BEAM SEAT DETAIL


STEEL TEST FRAME
HYDRAULIC JACKS
ROLLING SUPPORT
ADJUSTABLE PINNED SUPPORT
TEST TEE BEAM
CONCRETE SUPPORT PEDESTALS

WEST ELEVATION


LATERAL SUPPORT FRAME
ROLLING SUPPORT
LABORATORY STRUCTURAL FLOOR

NORTH ELEVATION

FIGURE 3.7

TYPICAL TEST SET UP

CHAPTER IV

TEST RESULTS

The results of the tests of twelve tee beams are presented in this chapter in tabular, graphical and photographic form. The values plotted were derived from readings taken during testing with the use of a survey level, electrical resistance strain gauges, Demec strain gauges, and the Amsler loading apparatus, and are tabulated in Appendix B.

4.1 Summary of Test Results

Table 4.1 gives simplified descriptions of the shear reinforcement details of the beams, and corresponding failure loads. Table 4.2 compares the observed ultimate moments with theoretical values based on Eq. 18-3 of the 1971 ACI Building Code(1), a strain-compatibility analysis, and the assumption of a stress of 275 ksi in the prestressing strand at failure. Sample calculations of these moments are given in Appendix C. In all cases the non-prestressed tensile reinforcement was considered to contribute to moment capacity according to Sec. 18.7.2 of the ACI Code(1). Also in this table the failure mode of each beam is described as either shear, shear-compression, or flexural. This classification was made on the simplistic, descriptive basis explained in Sec. 5.2 to facilitate the evaluation of the shear reinforcement arrangements used.

4.2 Load-Deflection Relationships

Figures 4.1.1 to 4.1.3 illustrate the relationships between moment and centerline deflections. For clarity, the beams are divided into three groups of four and each curve is referenced with the corresponding beam number. These groups are termed "Casting Groups" one (long beams cast singly), two (short beams cast in tandem with Linder's), and three (short beams cast in pairs in tandem). Deflection readings were also taken at the load points such that the three readings could be used to calculate an average curvature in the pure moment region. The resulting moment-curvature relationships are plotted on Figures 4.2.1 to 4.2.3.

4.3 Strain Distribution

Strain distributions within beam sections, as calculated from Demec strain gauge readings, are shown for selected loads in Figures 4.3.1 to 4.3.3. Demec point locations near beam centerlines are as depicted in Figure 3.4. In addition, the strain in the top fibre of the flange given by Demec readings is plotted against moment in Figures 4.4.1 to 4.4.3.

4.4 Moment-Reinforcement Strain Relationships

The remaining figures show the relationships between applied moment and strain in the reinforcement obtained from readings of the strain gauges mounted on the prestressing strand and shear reinforcement. General locations of these gauges are shown in Figure 4.5. Individual curves are referenced with beam number and gauge number in order that the exact location of any gauge can be found in Appendix B.

Strains in the prestressing strand are plotted on Figures 4.6.1 to 4.7.4. The first three figures deal with strain in the strand at centerline, while the rest deal with the other four general locations. Figures 4.8.1 to 4.11 illustrate the relationships between moment and strain in the full-depth #3 stirrups, the upper web #2 stirrups, and the lower web #2 stirrups.

4.5 Cracking and Failure Patterns

Plates 4.1 to 4.12 consist of photographs of each of the beams at two stages of loading. The first load is one at which the general cracking pattern has developed, and the second is the failure load. Close-up views of the failure regions of beams AD-1, AD-7, and AD-8 are shown in Plates 4.13 to 4.15 to illustrate the three modes of failure by which the beams are classified.

TABLE 4.1

SUMMARY OF TEST RESULTS

BEAM NO.	SHEAR SPAN ft	STIRRUP SLOPE degrees	STIRRUPS PER POST	AVERAGE SPACING		FAILURE LOAD kips
				UPPER in	LOWER in	
AD-1	6	90	2	none	none	19.0
AD-2	6	90	2	none	none	20.0
AD-3	6	45	2	none	none	29.0
AD-4	6	45	2	2.13	3.00	29.1
AD-5	4	90	3	1.25	2.00	35.0
AD-6	4	45	3	1.25	1.50	42.0
AD-7	4	45	4	none	none	42.5
AD-8	4	45	4	1.50	1.75	43.25
AD-9	4	45	3	none	none	38.0
AD-10	4	90	3	1.00	1.50	33.0
AD-11	4	60	3	none	none	31.0
AD-12	4	60	3	1.00	1.50	39.0

TABLE 4.2

COMPARISON OF OBSERVED AND THEORETICAL ULTIMATE MOMENTS

BEAM NO.	FAILURE TYPE	FAILURE LOAD kips	FAILURE MOMENT in kips	THEOR. ULTIMATE MOMENT		
				ACI CODE in kips	STRAIN COMPAT. in kips	275 ksi in kips
AD-1	SHEAR	19.0	1368.0	1650.0	1896.2	1900.2
AD-2	SHEAR	20.0	1440.0	1650.0	1910.9	1900.2
AD-3	SHEAR-COMP	29.0	2088.0	1650.0	1904.2	1900.2
AD-4	FLEXURE	29.1	2095.2	1650.0	1900.1	1900.2
AD-5	SHEAR	35.0	1680.0	1650.0	1900.6	1900.2
AD-6	FLEXURE	42.0	2016.0	1650.0	1915.7	1900.2
AD-7	SHEAR-COMP	42.5	2040.0	1650.0	1904.5	1900.2
AD-8	FLEXURE	43.25	2076.0	1650.0	1900.2	1900.2
AD-9	SHEAR-COMP	38.0	1824.0	1650.0	1903.8	1900.2
AD-10	SHEAR	33.0	1584.0	1650.0	1906.4	1900.2
AD-11	SHEAR	31.0	1488.0	1650.0	1897.8	1900.2
AD-12	SHEAR-COMP	39.0	1872.0	1650.0	1911.9	1900.2

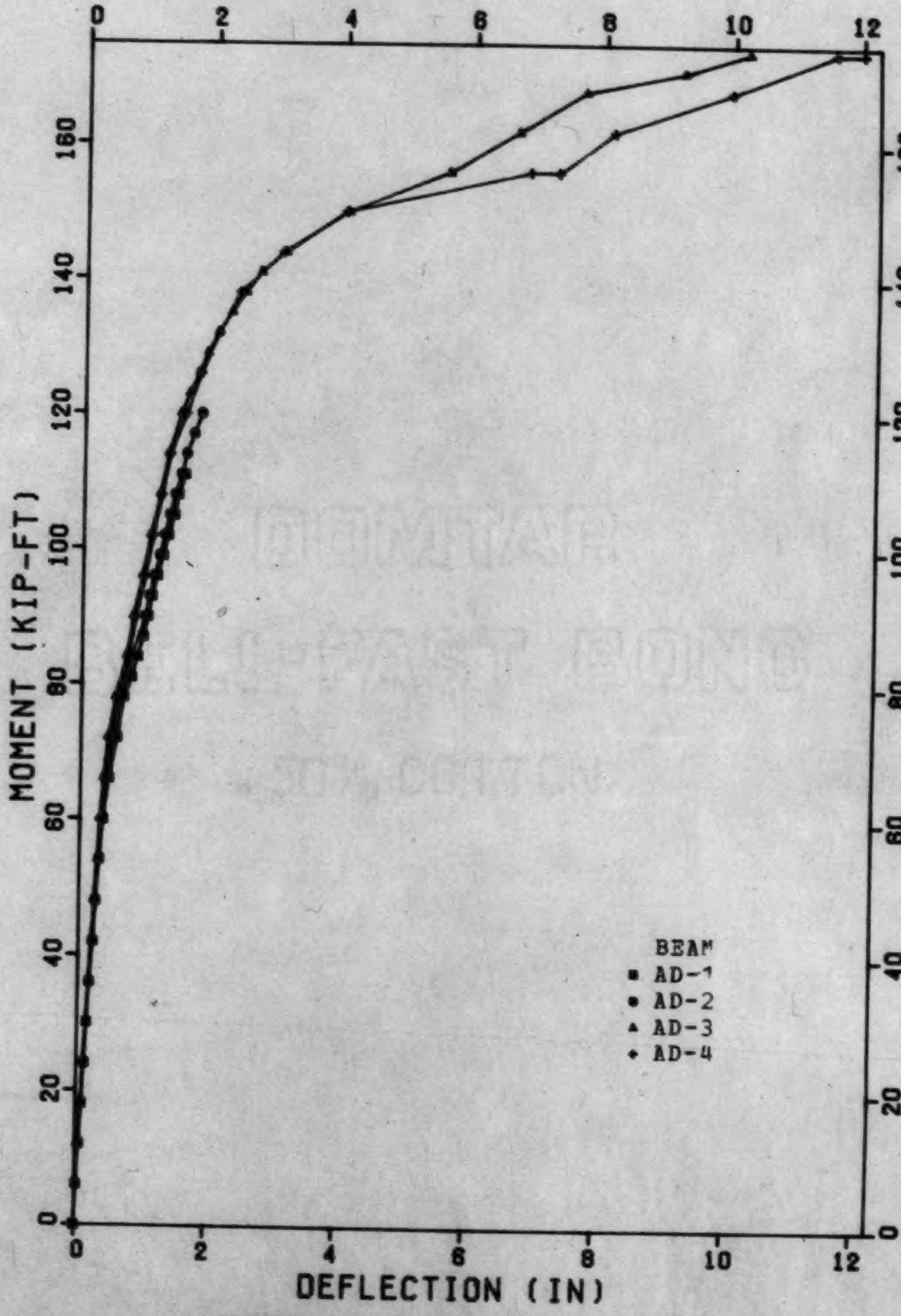


FIGURE 4.1.1 CASTING GROUP ONE

APPLIED MOMENT VS. CENTERLINE DEFLECTION

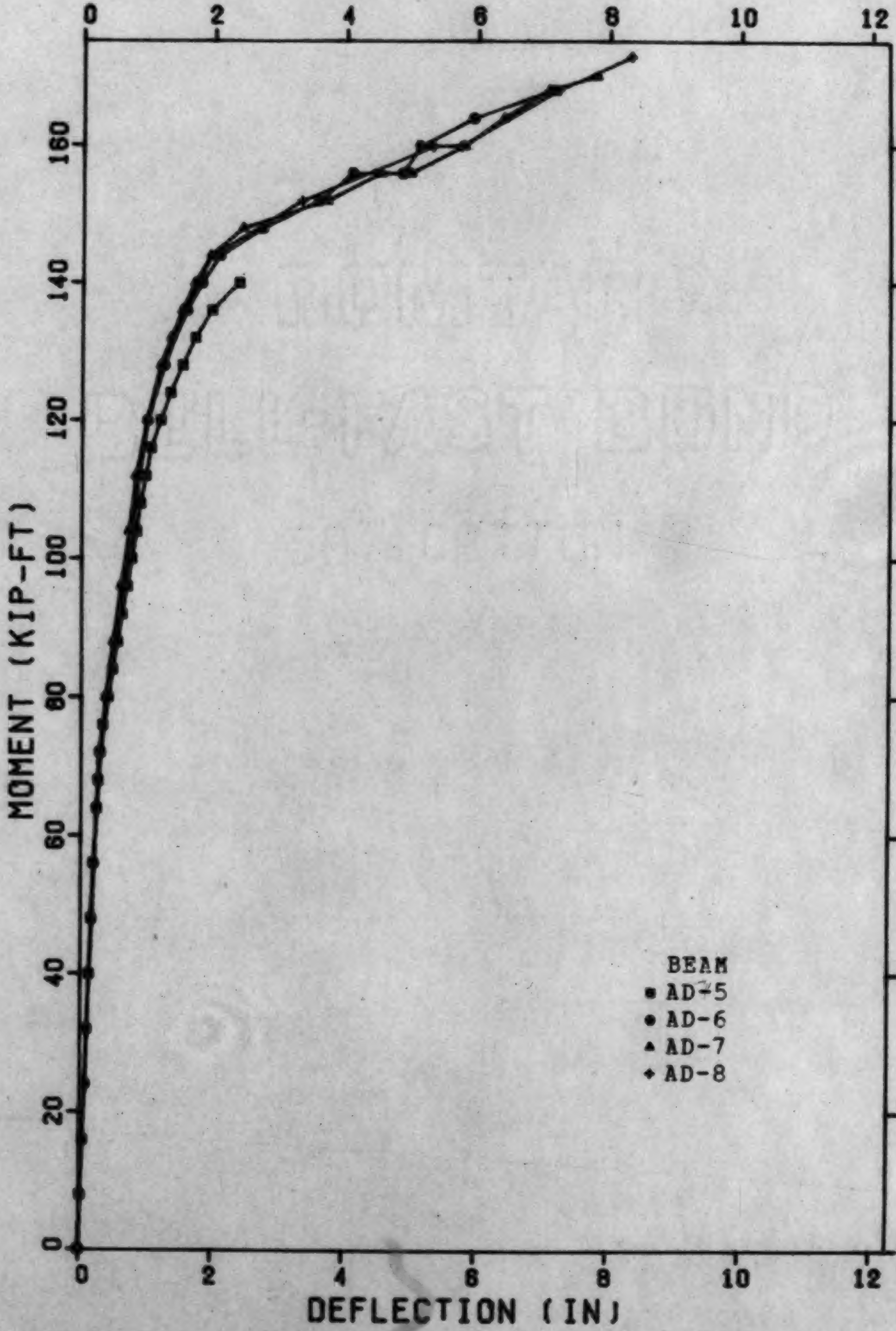


FIGURE 4.1.2 CASTING GROUP TWO

APPLIED MOMENT VS. CENTERLINE DEFLECTION

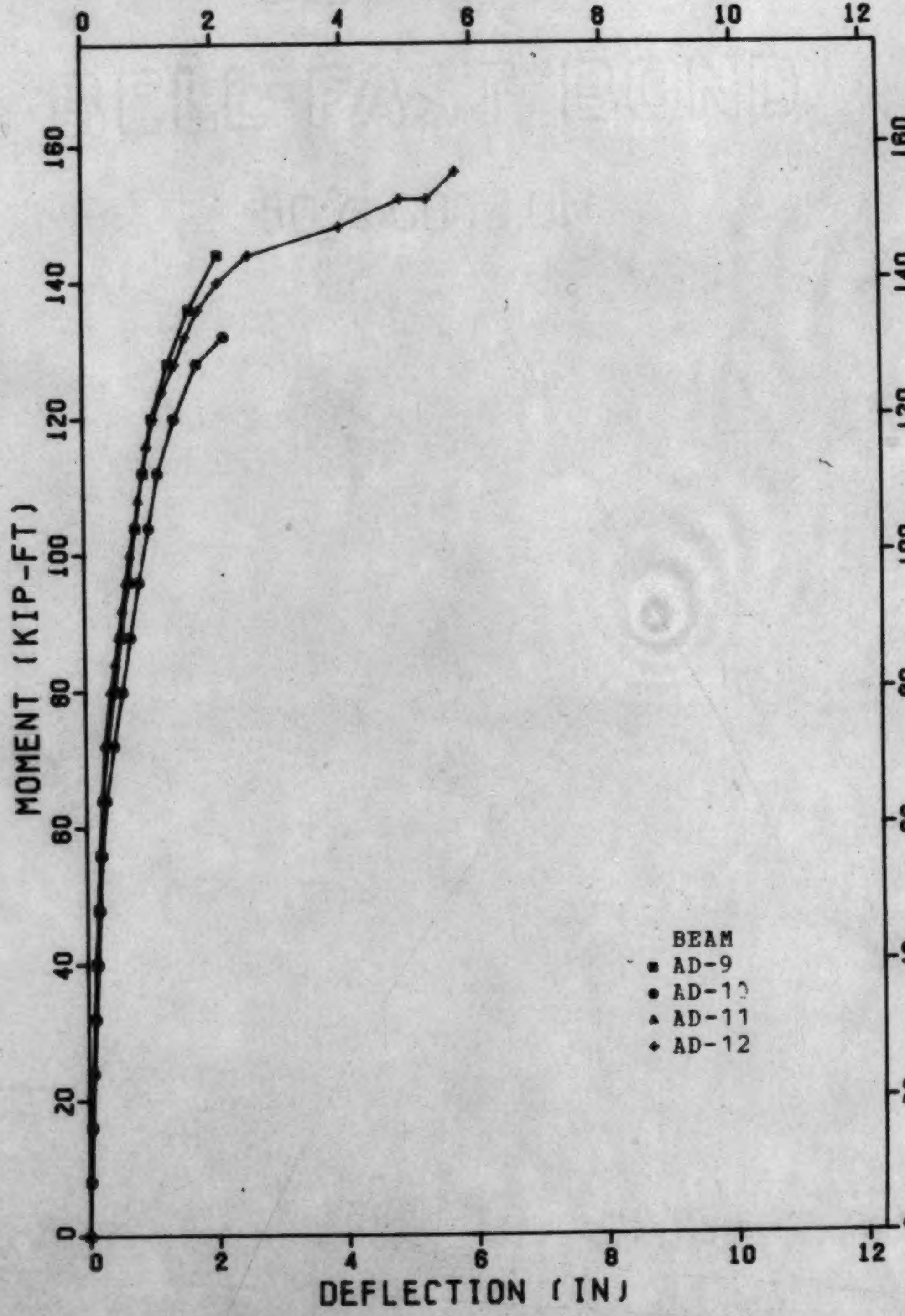


FIGURE 4.1.3 CASTING GROUP THREE

APPLIED MOMENT VS. CENTERLINE DEFLECTION

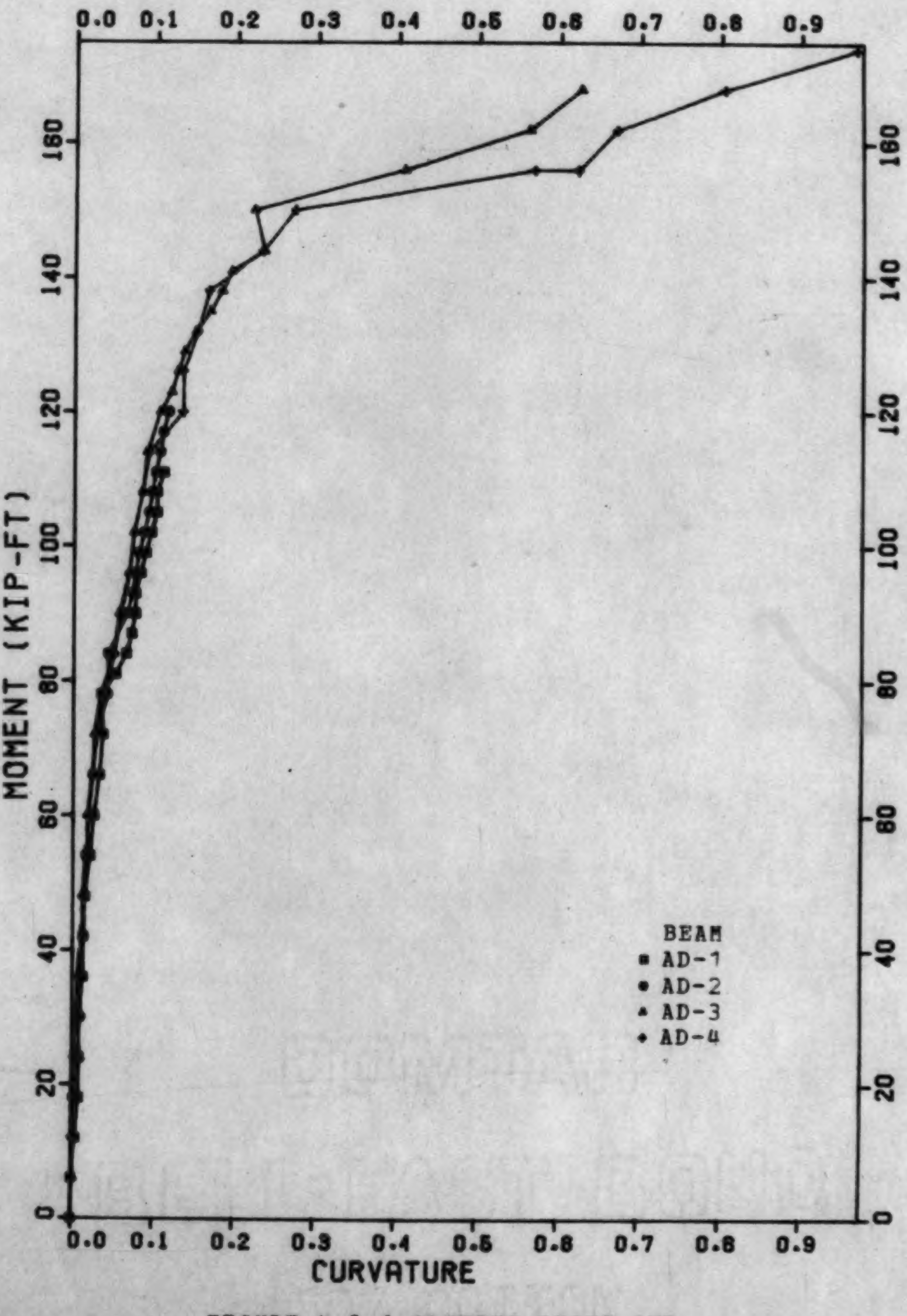


FIGURE 4.2.1 CASTING GROUP ONE

APPLIED MOMENT VS. AVERAGE CURVATURE (in^{-1}*10^{-3})

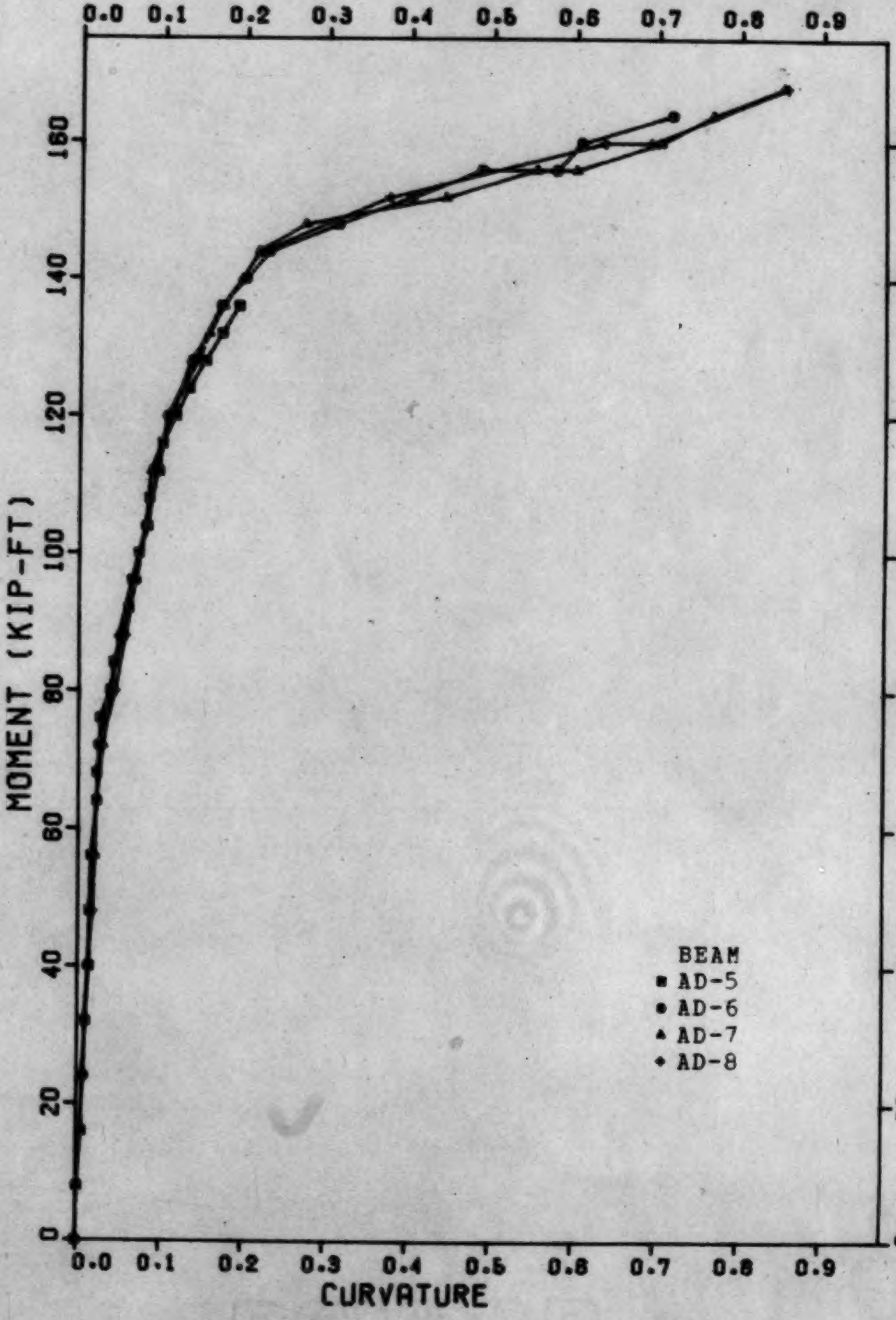


FIGURE 4.2.2 CASTING GROUP TWO

APPLIED MOMENT VS. AVERAGE CURVATURE ($in^{-1} * 10^{-3}$)

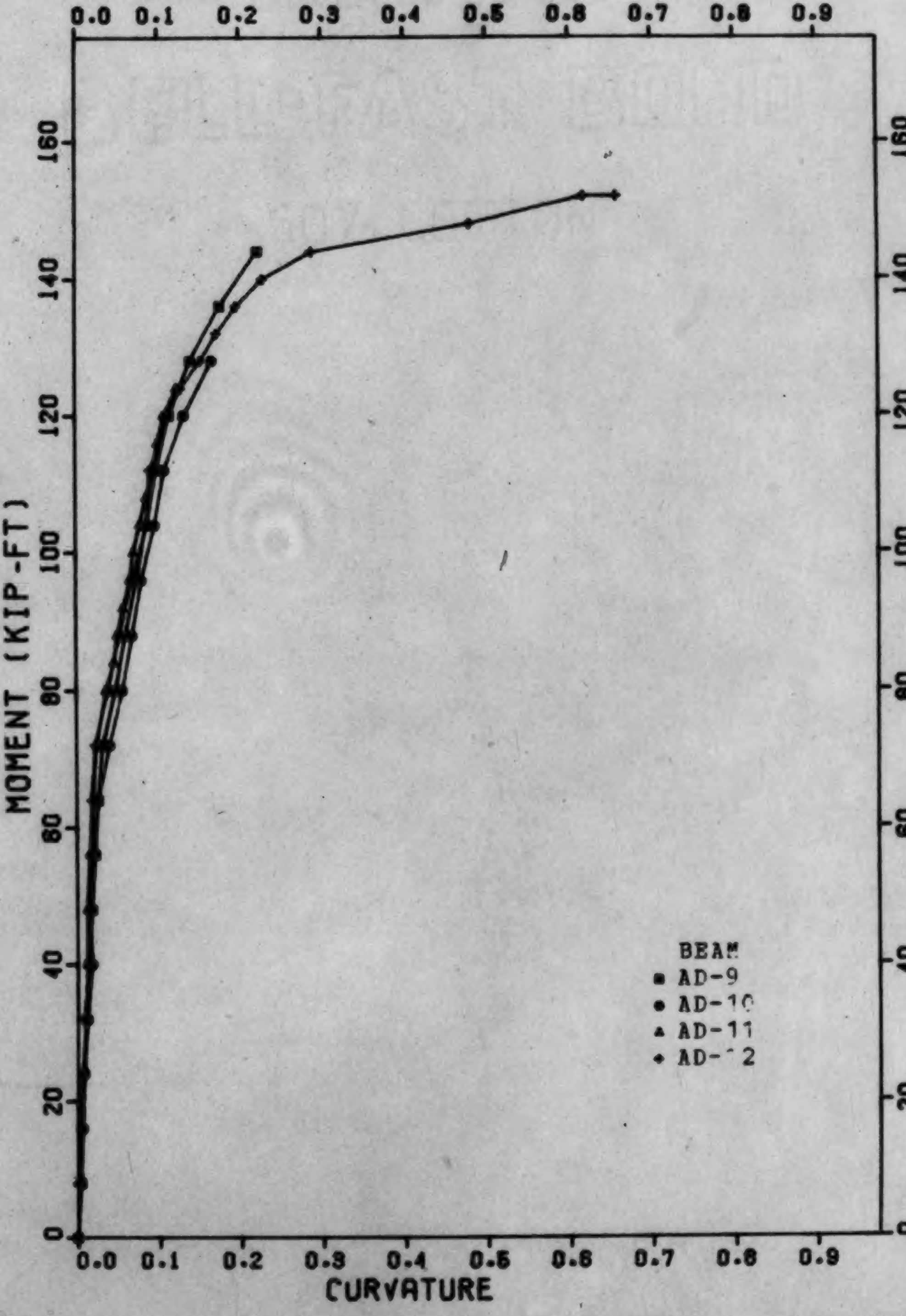


FIGURE 4.2.3 CASTING GROUP THREE

APPLIED MOMENT VS. AVERAGE CURVATURE ($in^{-1}*10^{-3}$)

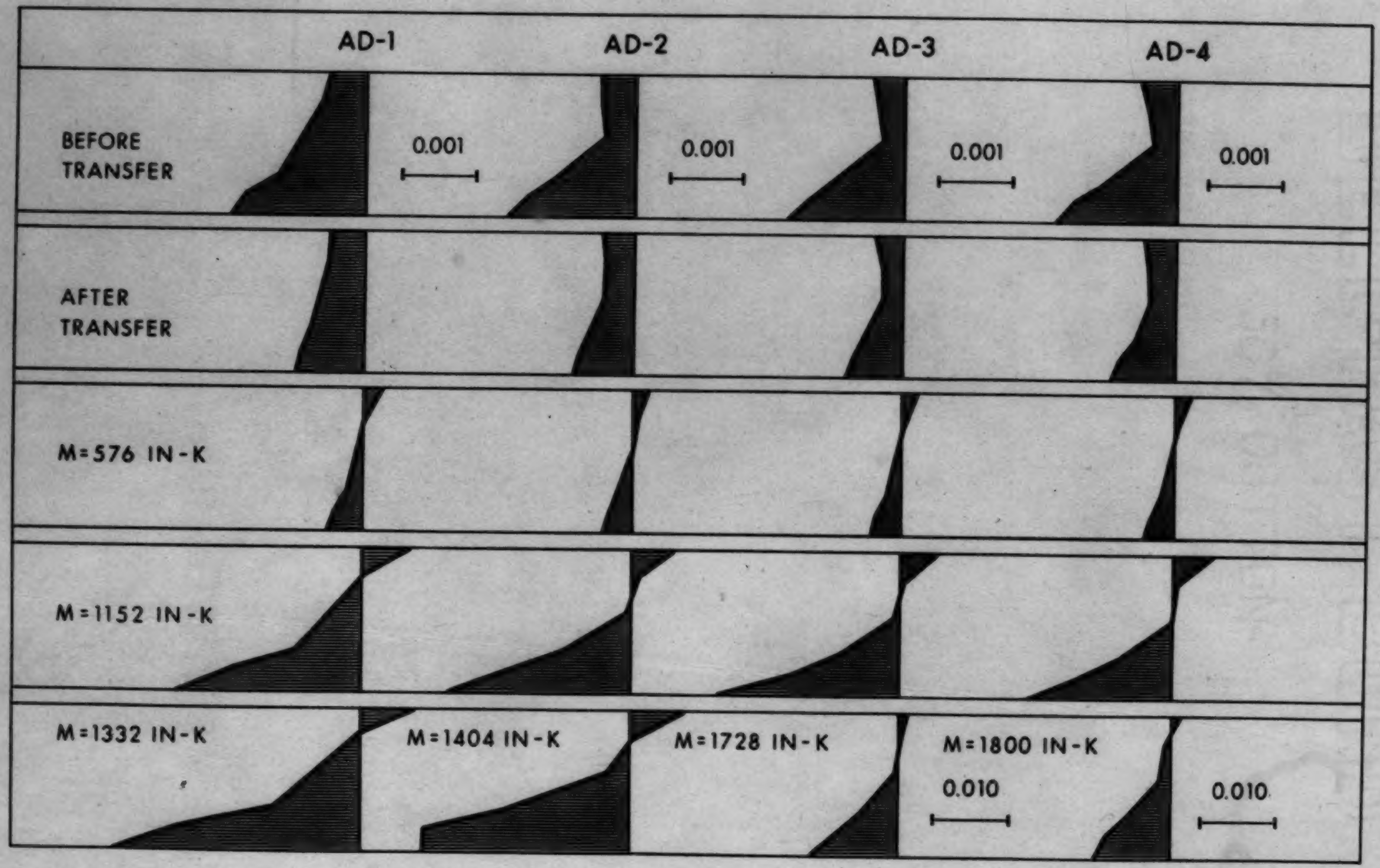


FIGURE 4.3.1 CASTING GROUP ONE STRAIN DISTRIBUTION

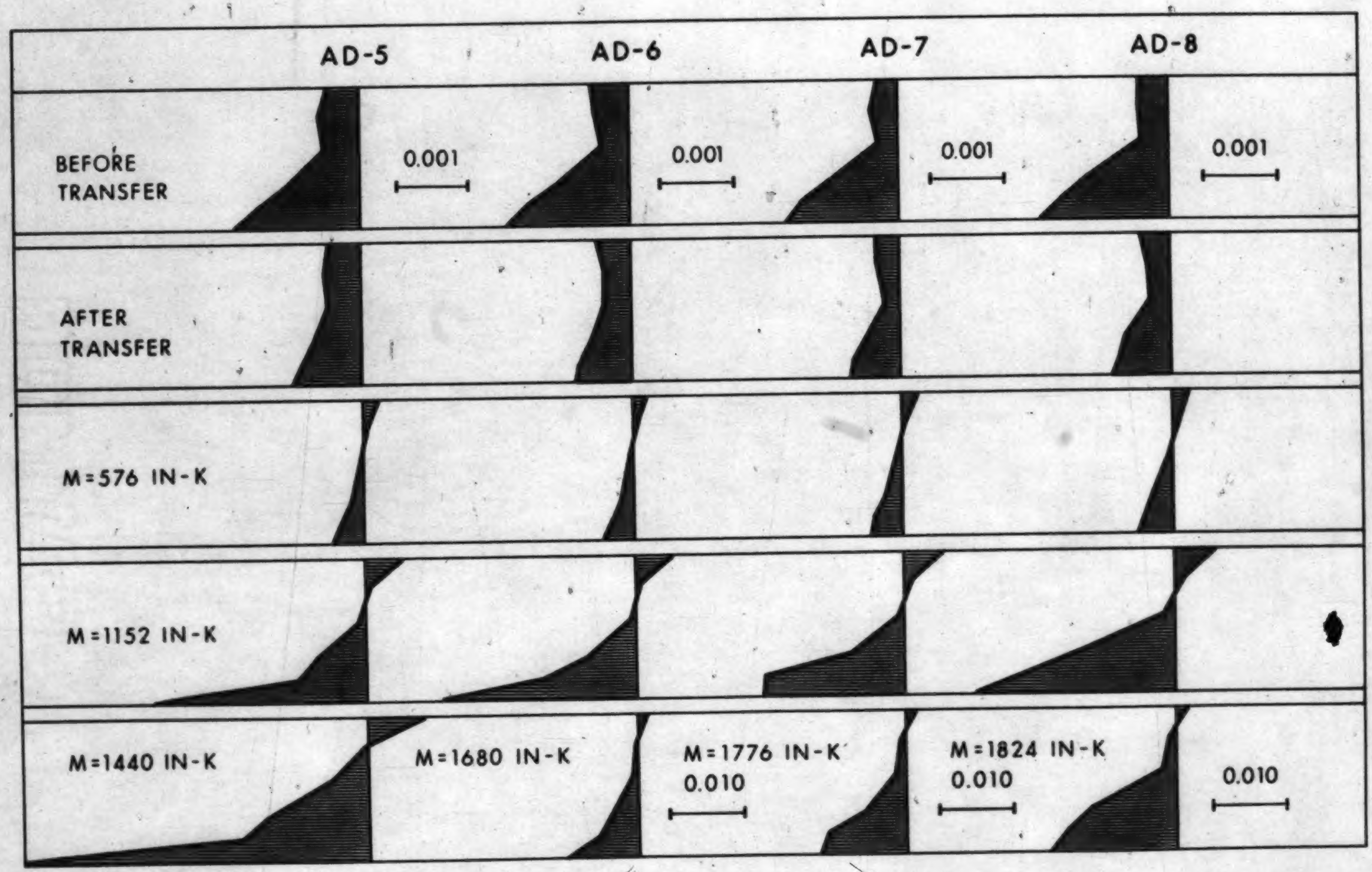


FIGURE 4.3.2 CASTING GROUP TWO STRAIN DISTRIBUTION

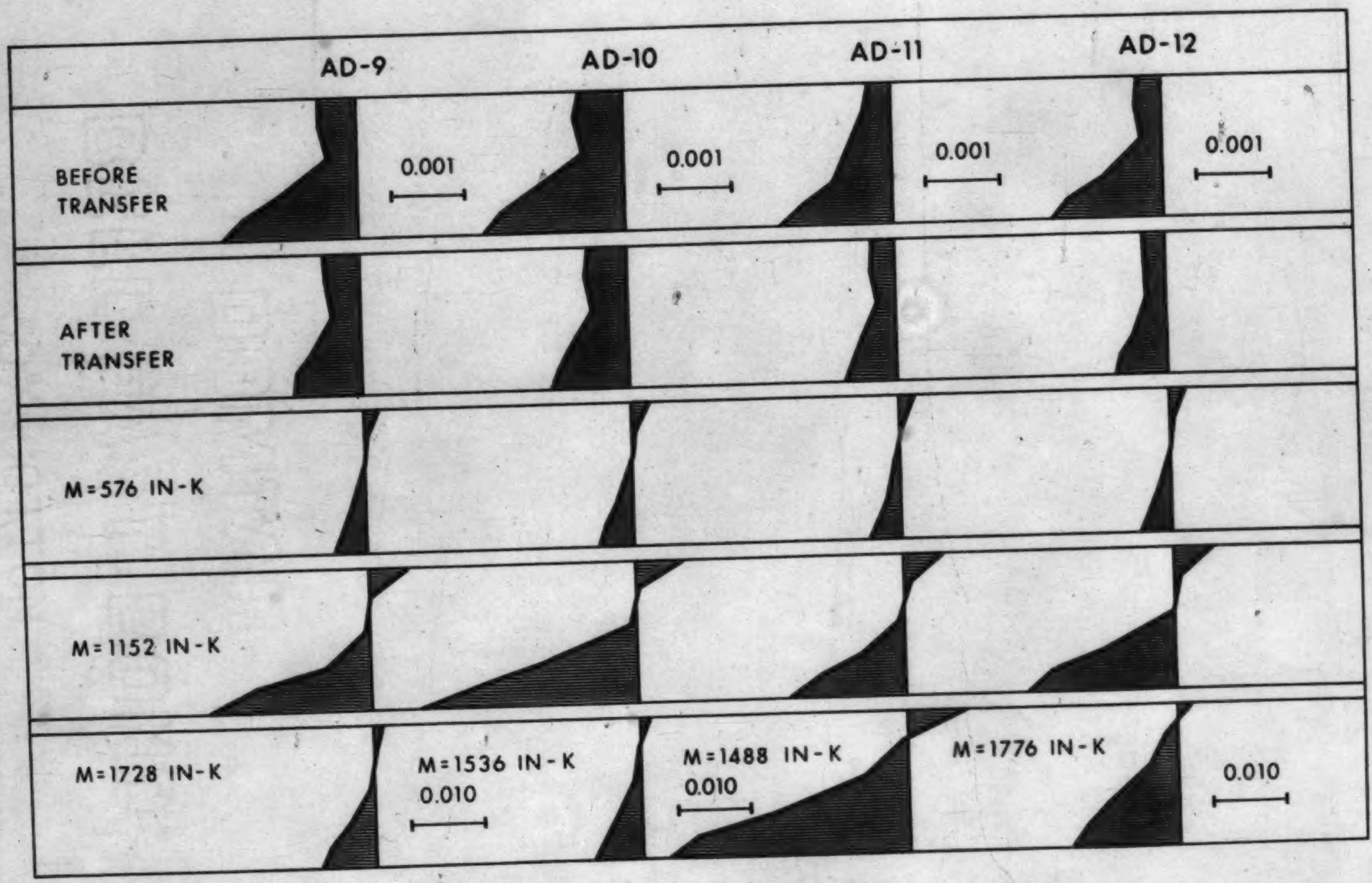


FIGURE 4.3.3 CASTING GROUP THREE STRAIN DISTRIBUTION

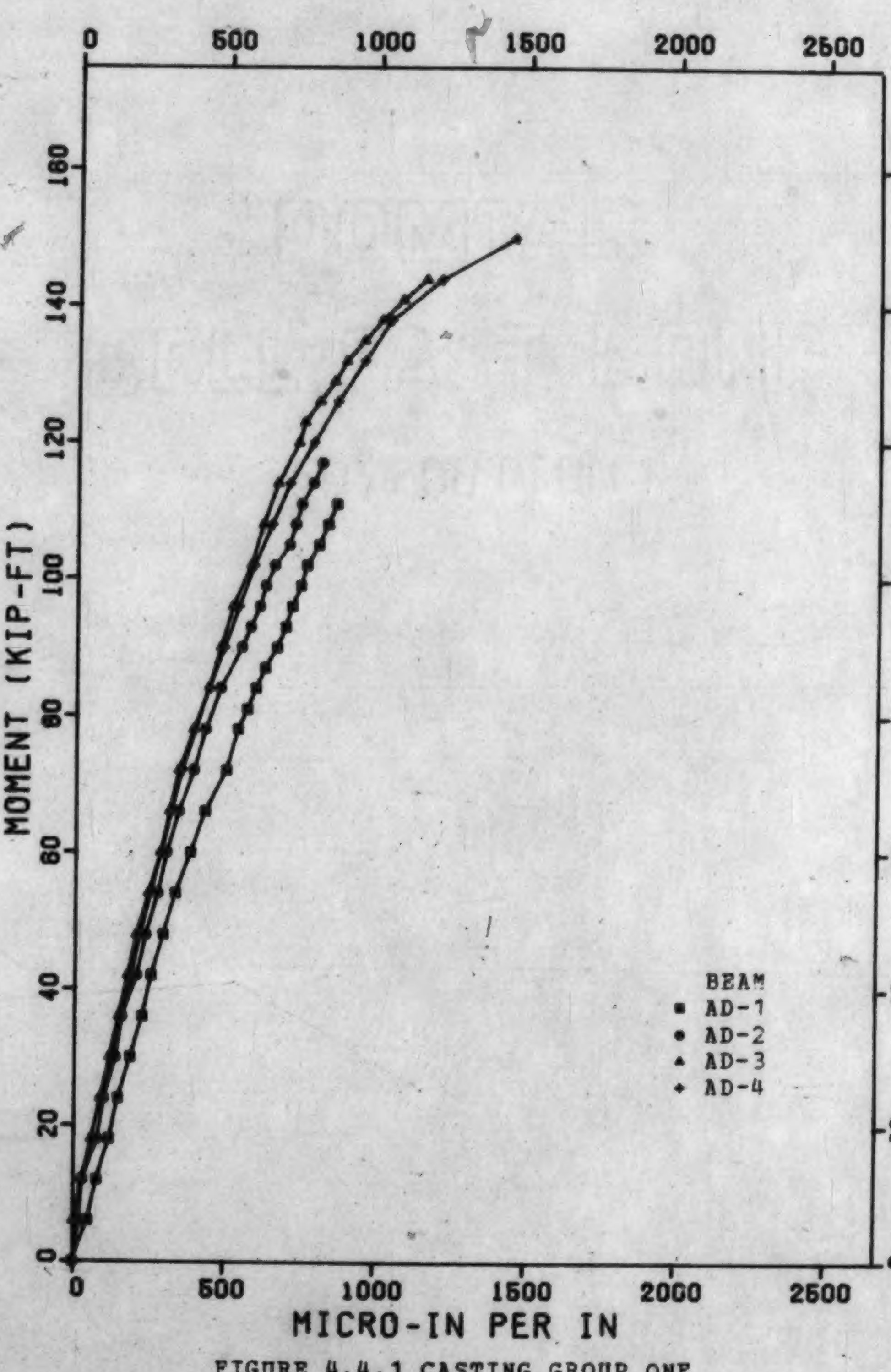


FIGURE 4.4.1 CASTING GROUP ONE

APPLIED MOMENT VS. STRAIN ON TOP SURFACE OF FLANGE

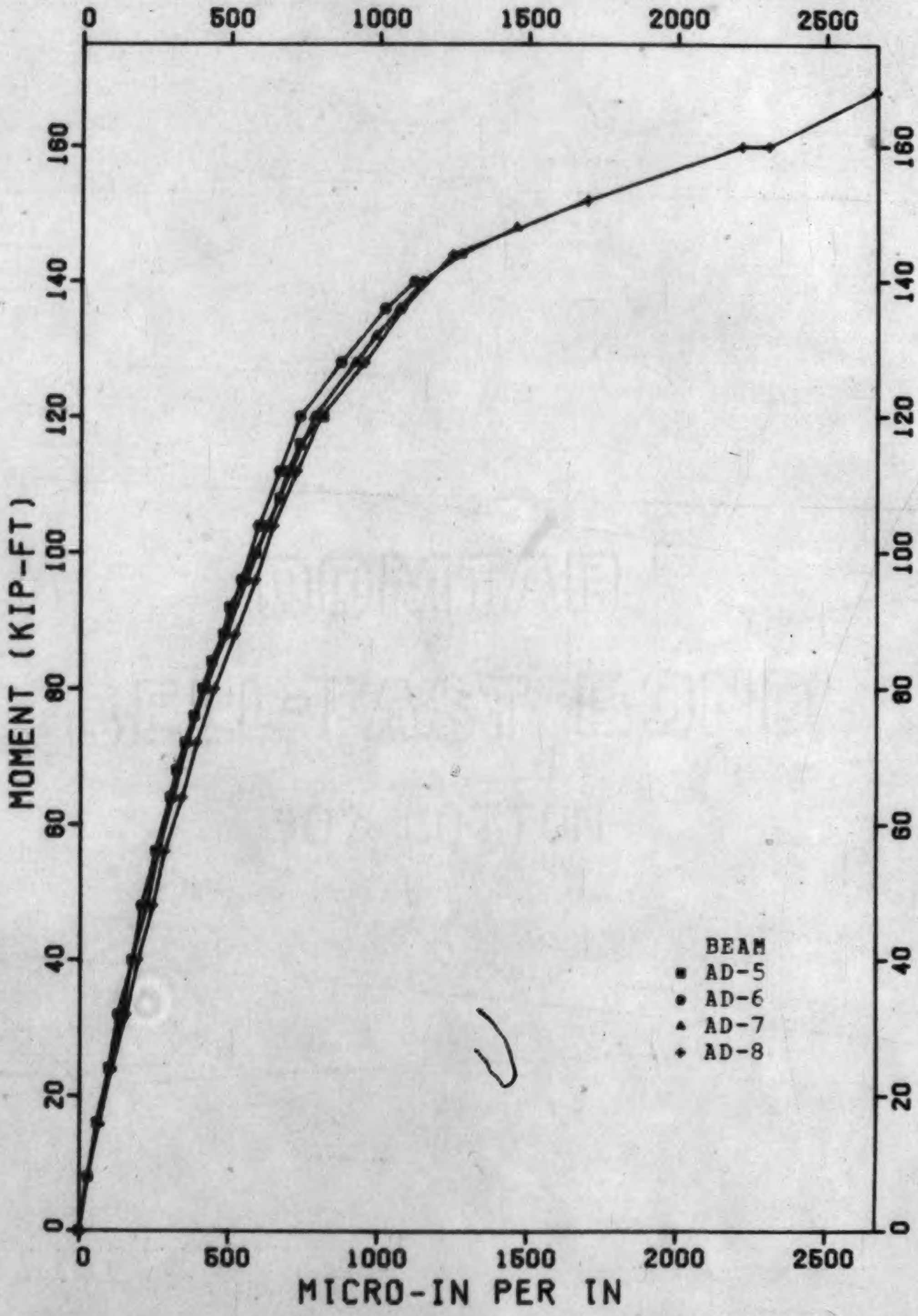


FIGURE 4.4.2 CASTING GROUP TWO

APPLIED MOMENT VS. STRAIN ON TOP SURFACE OF FLANGE

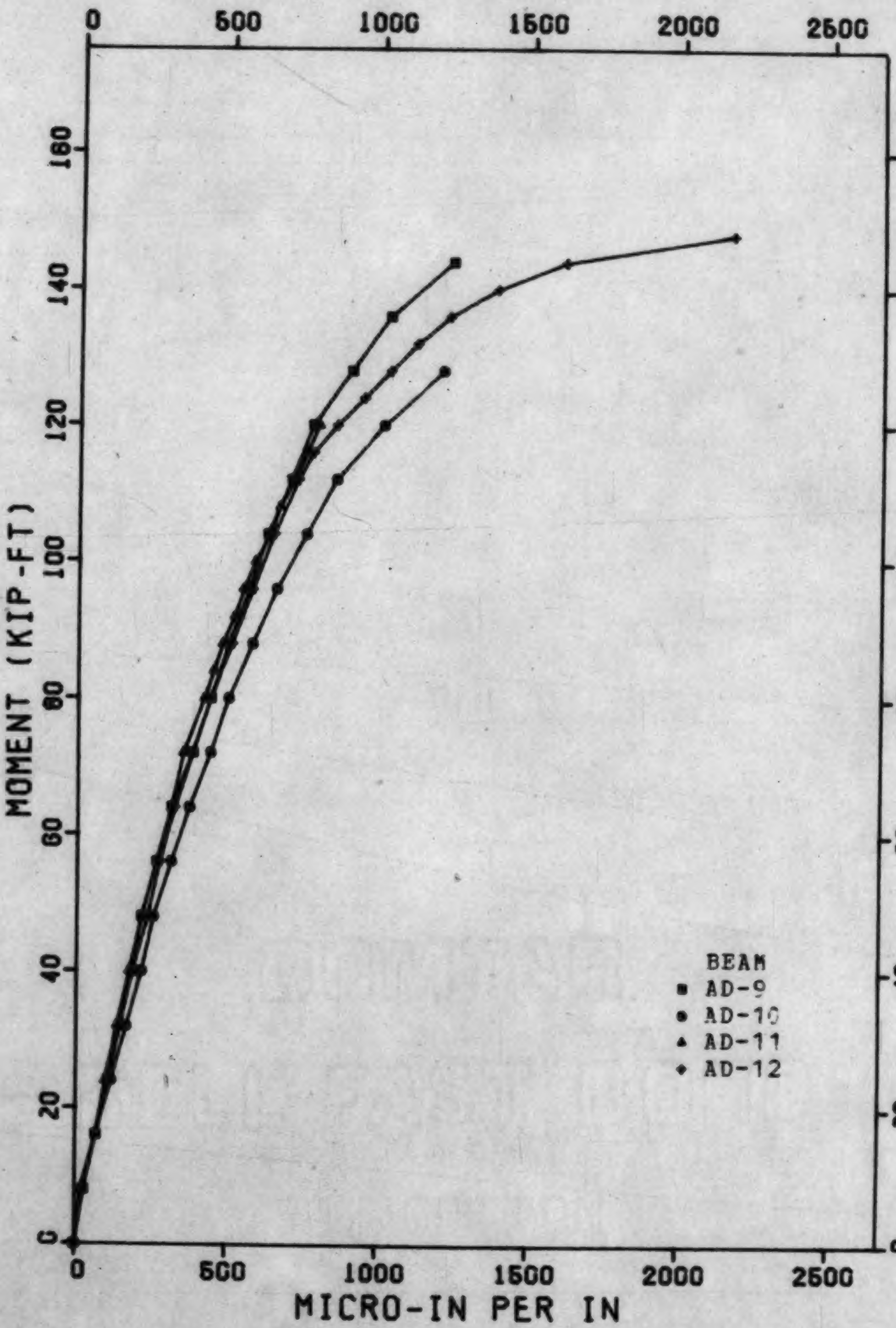
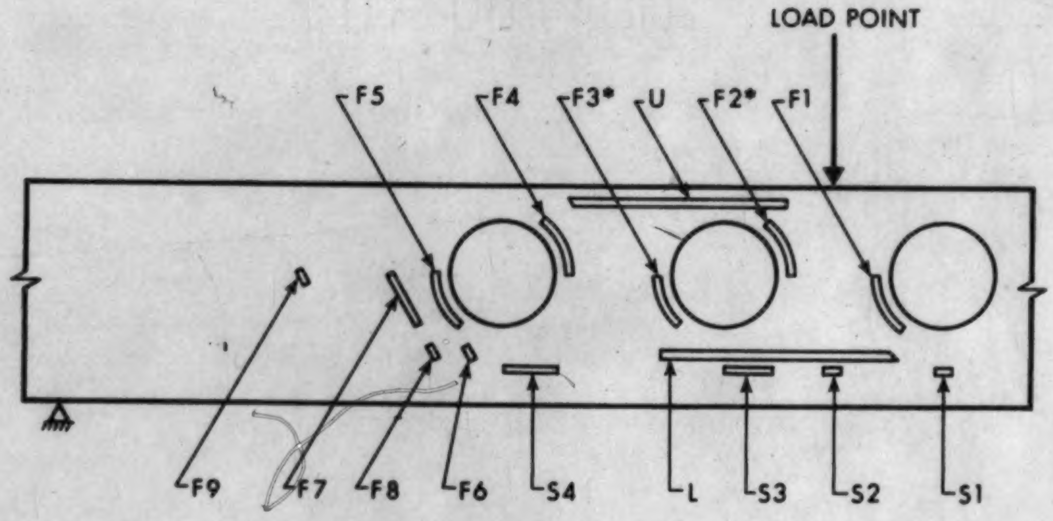


FIGURE 4.4.3 CASTING GROUP THREE

APPLIED MOMENT VS. STRAIN ON TOP SURFACE OF FLANGE


LOAD POINT
F5
F4
F3*
U
F2*
F1
F9
F7
F8
F6
S4
L
S3
S2
S1

* CASTING GROUP #1 ONLY

S1 to S4 STRAIN GAUGES ON PRESTRESSING STRAND
F1 to F9 STRAIN GAUGES ON FULL-DEPTH #3 STIRRUPS
U STRAIN GAUGES ON UPPER WEB #2 STIRRUPS
L STRAIN GAUGES ON LOWER WEB #2 STIRRUPS

FIGURE 4.5

GENERAL GAUGE LOCATIONS

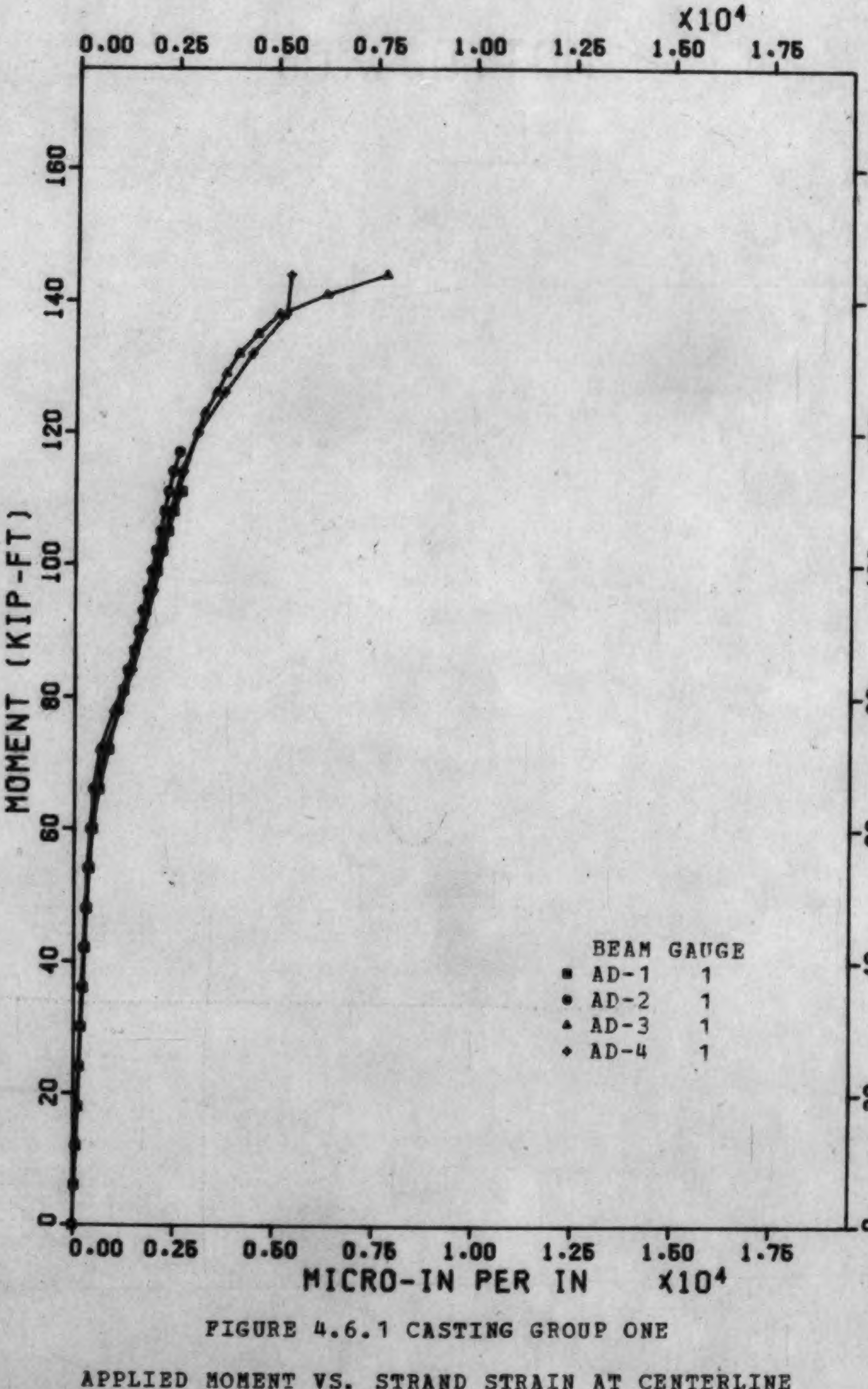


FIGURE 4.6.1 CASTING GROUP ONE

APPLIED MOMENT VS. STRAND STRAIN AT CENTERLINE

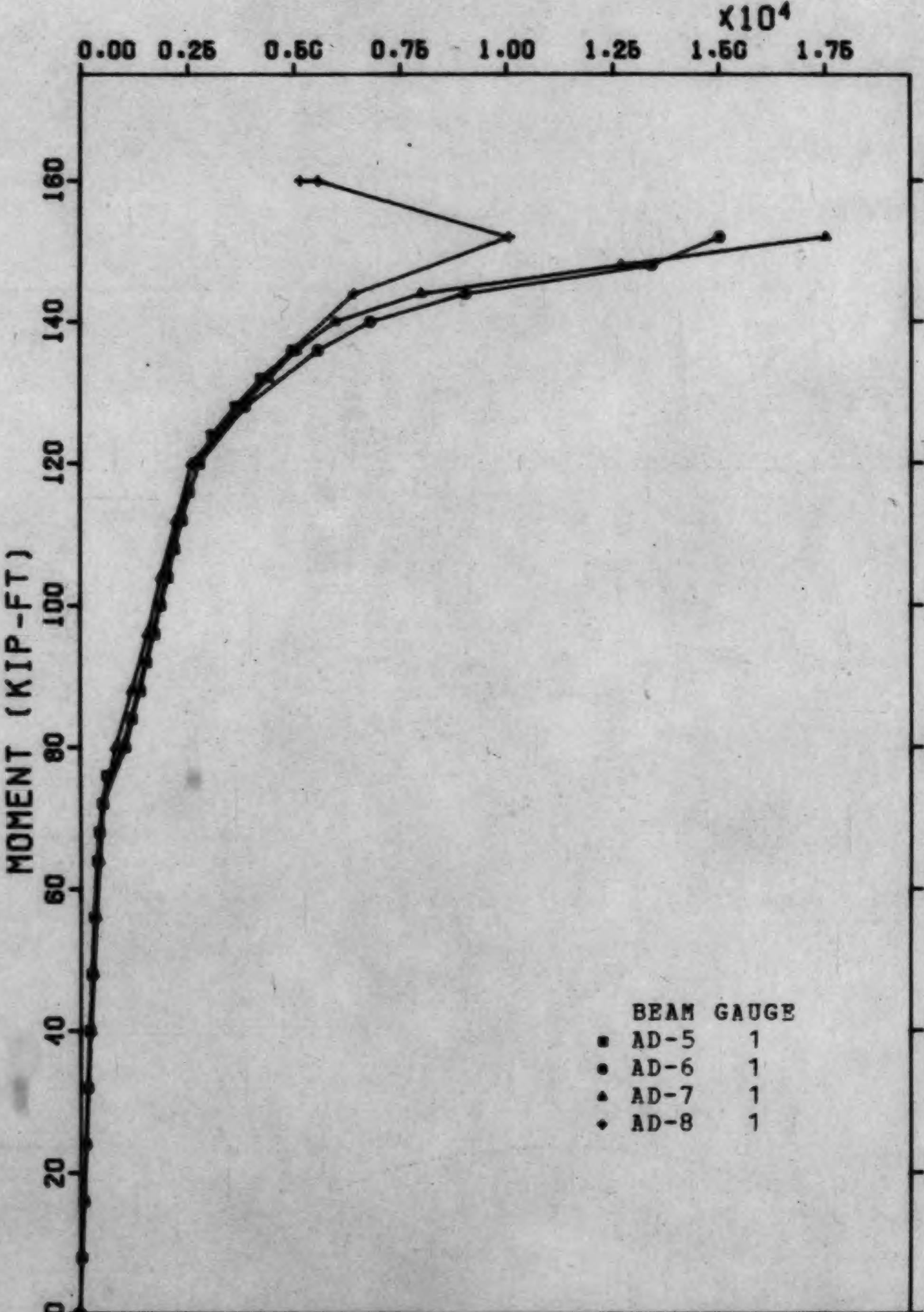


FIGURE 4.6.2 CASTING GROUP TWO

APPLIED MOMENT VS. STRAND STRAIN AT CENTERLINE

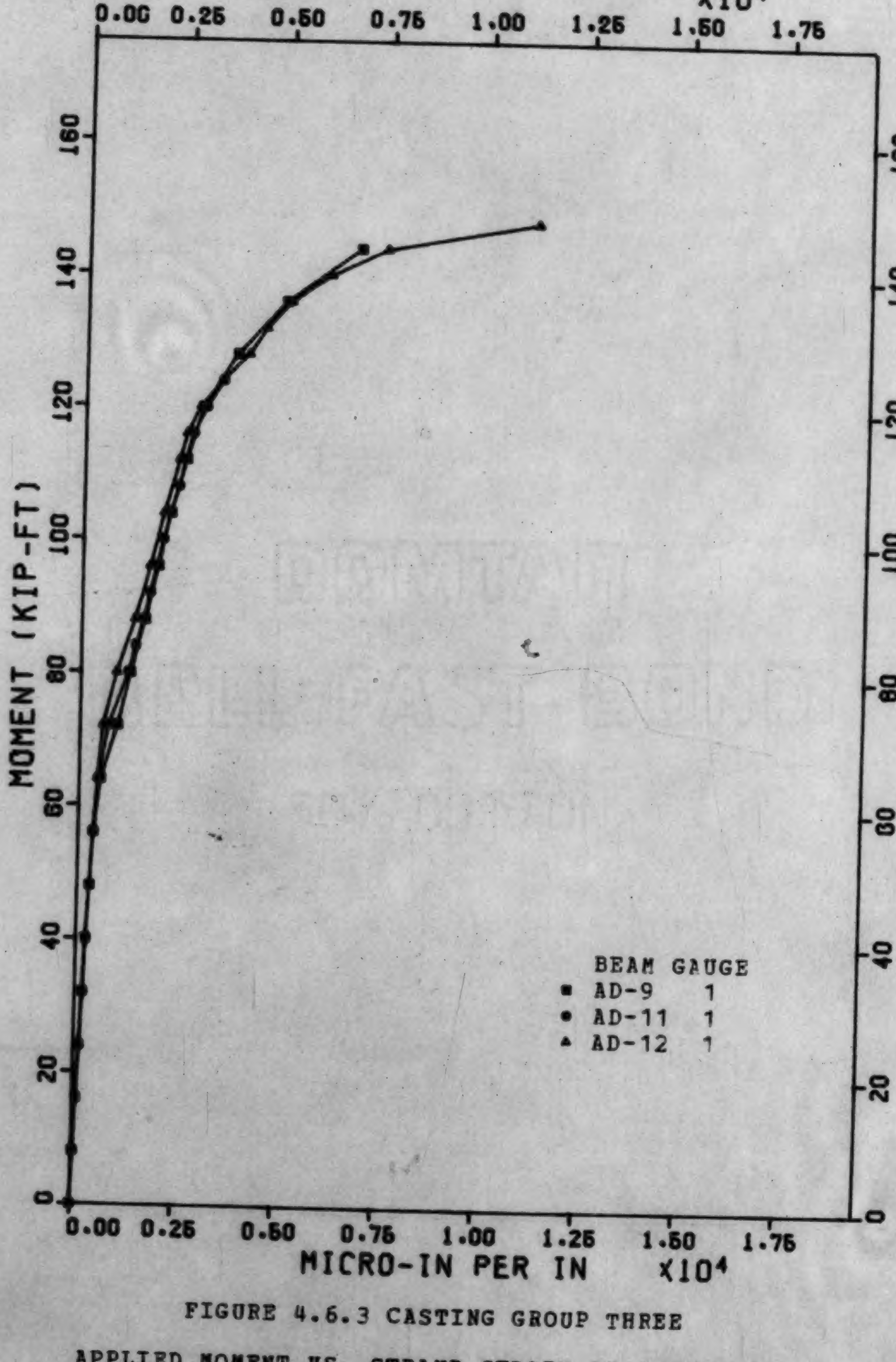


FIGURE 4.6.3 CASTING GROUP THREE

APPLIED MOMENT VS. STRAND STRAIN AT CENTERLINE

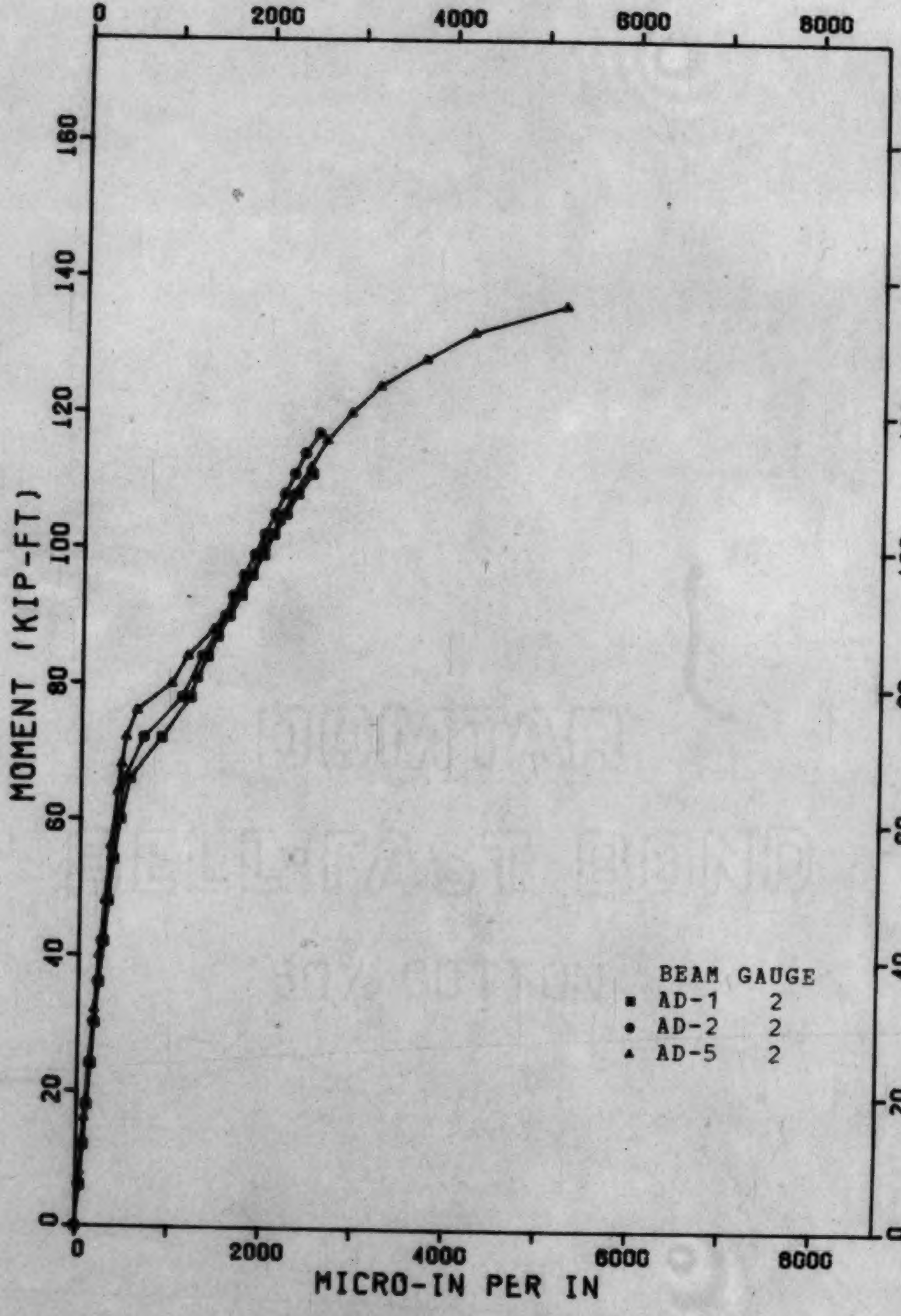


FIGURE 4.7.1

APPLIED MOMENT VS. STRAND STRAIN AT LOCATION 'S1'

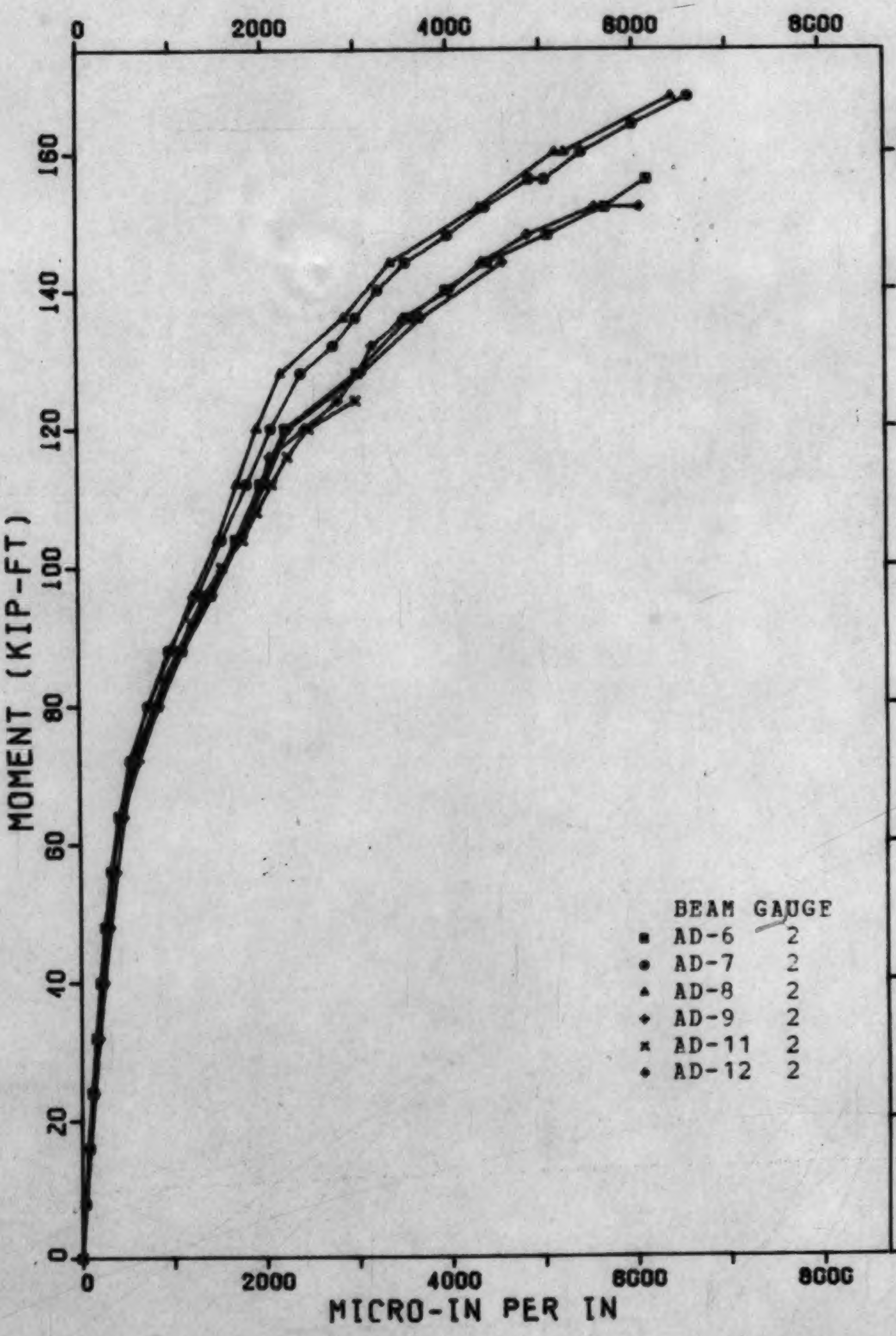


FIGURE 4.7.2

APPLIED MOMENT VS. STRAND STRAIN AT LOCATION 'S2'

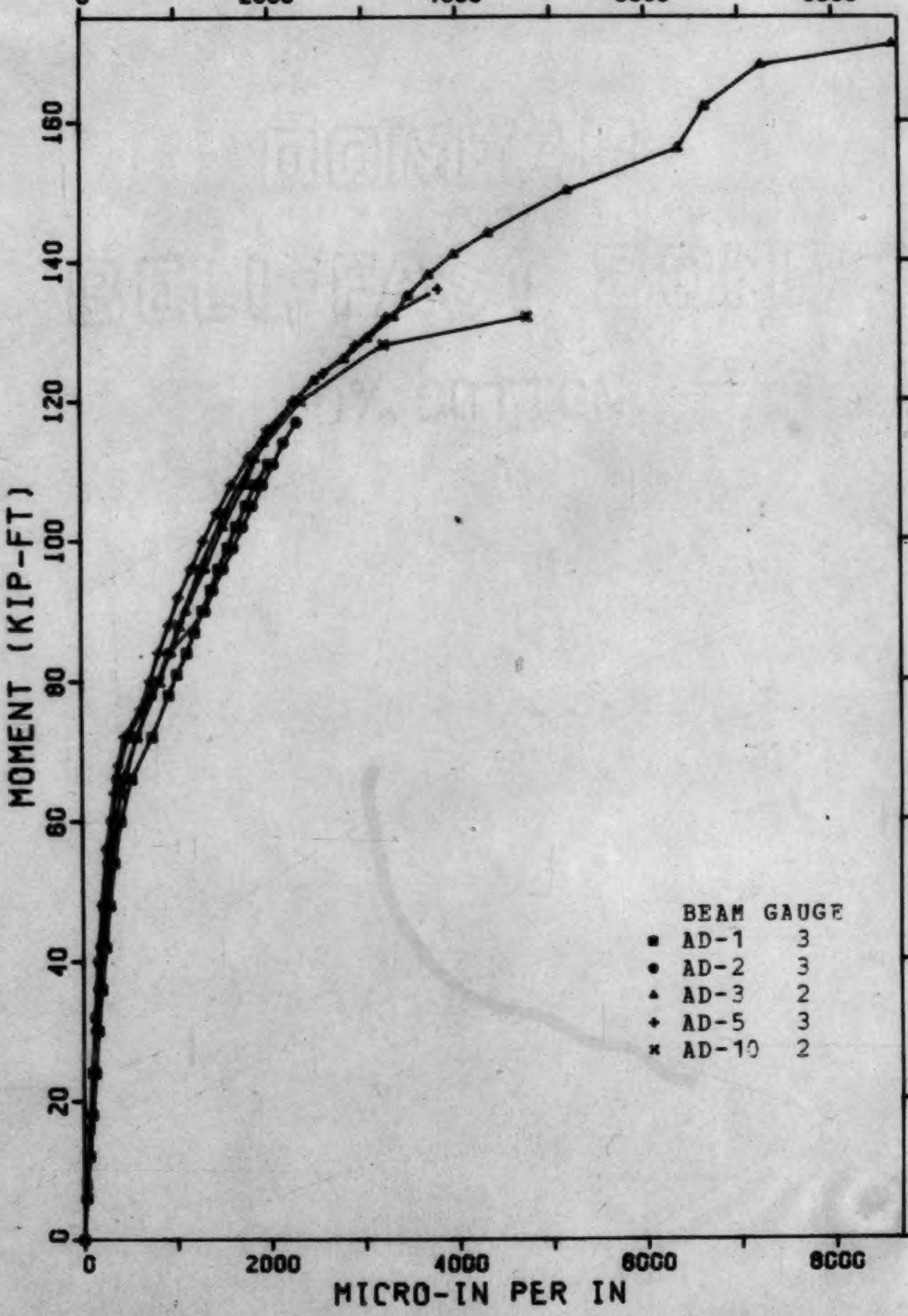


FIGURE 4.7.3

APPLIED MOMENT VS. STRAND STRAIN AT LOCATION 'S3'

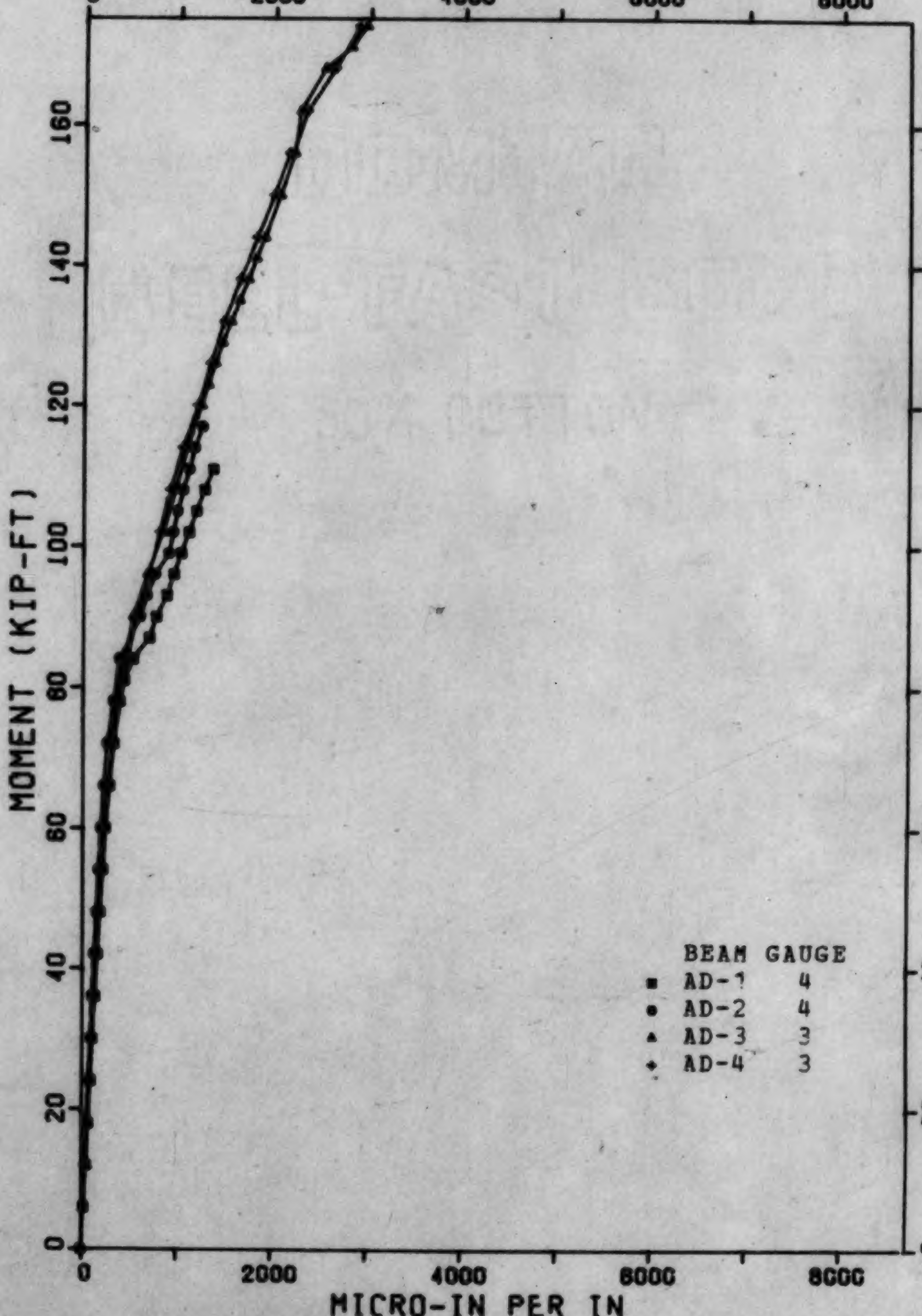


FIGURE 4.7.4

APPLIED MOMENT VS. STRAND STRAIN AT LOCATION 'S4'

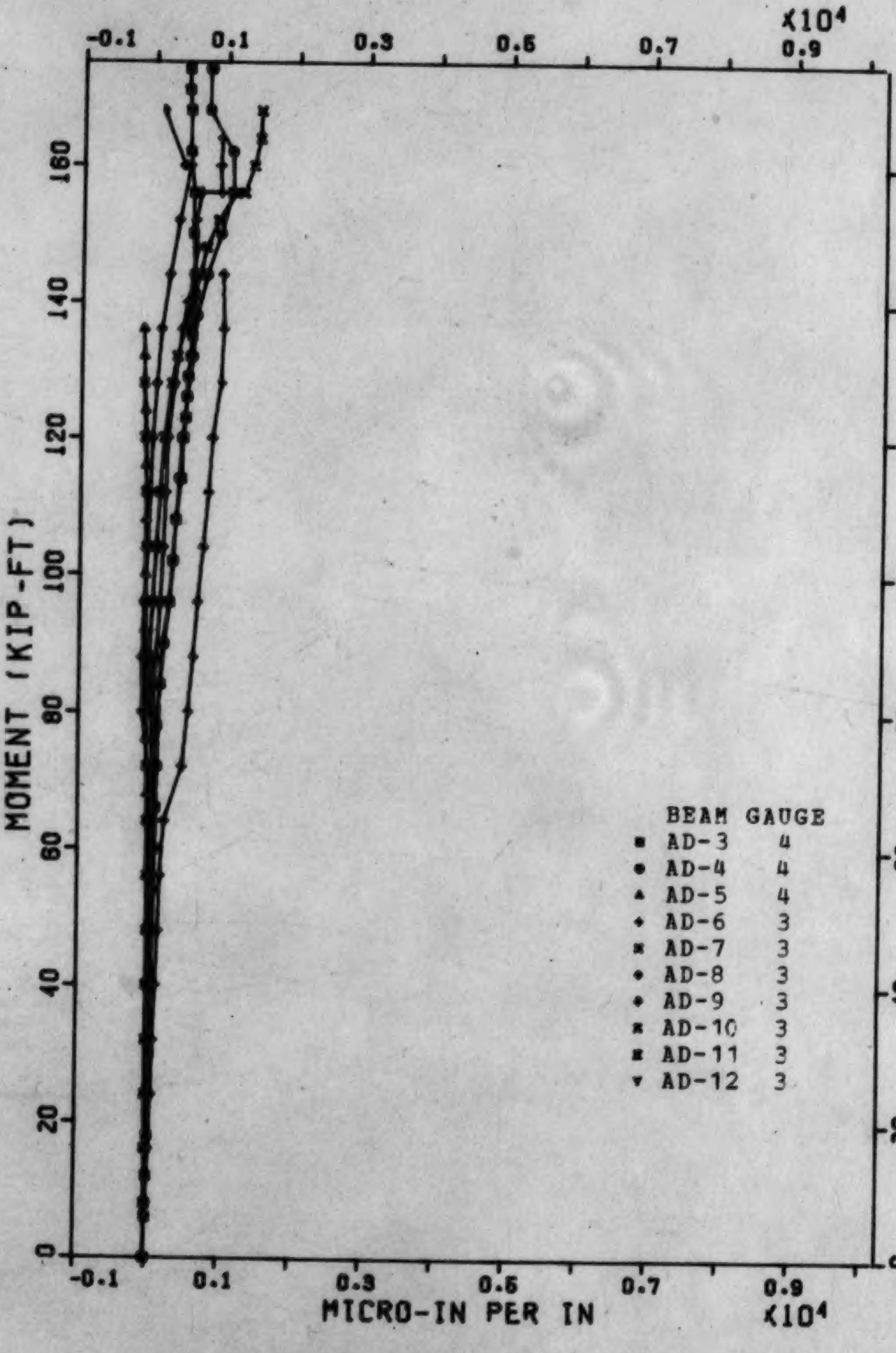


FIGURE 4.8.1

APPLIED MOMENT VS. STIRRUP STRAIN AT LOCATION 'P1'

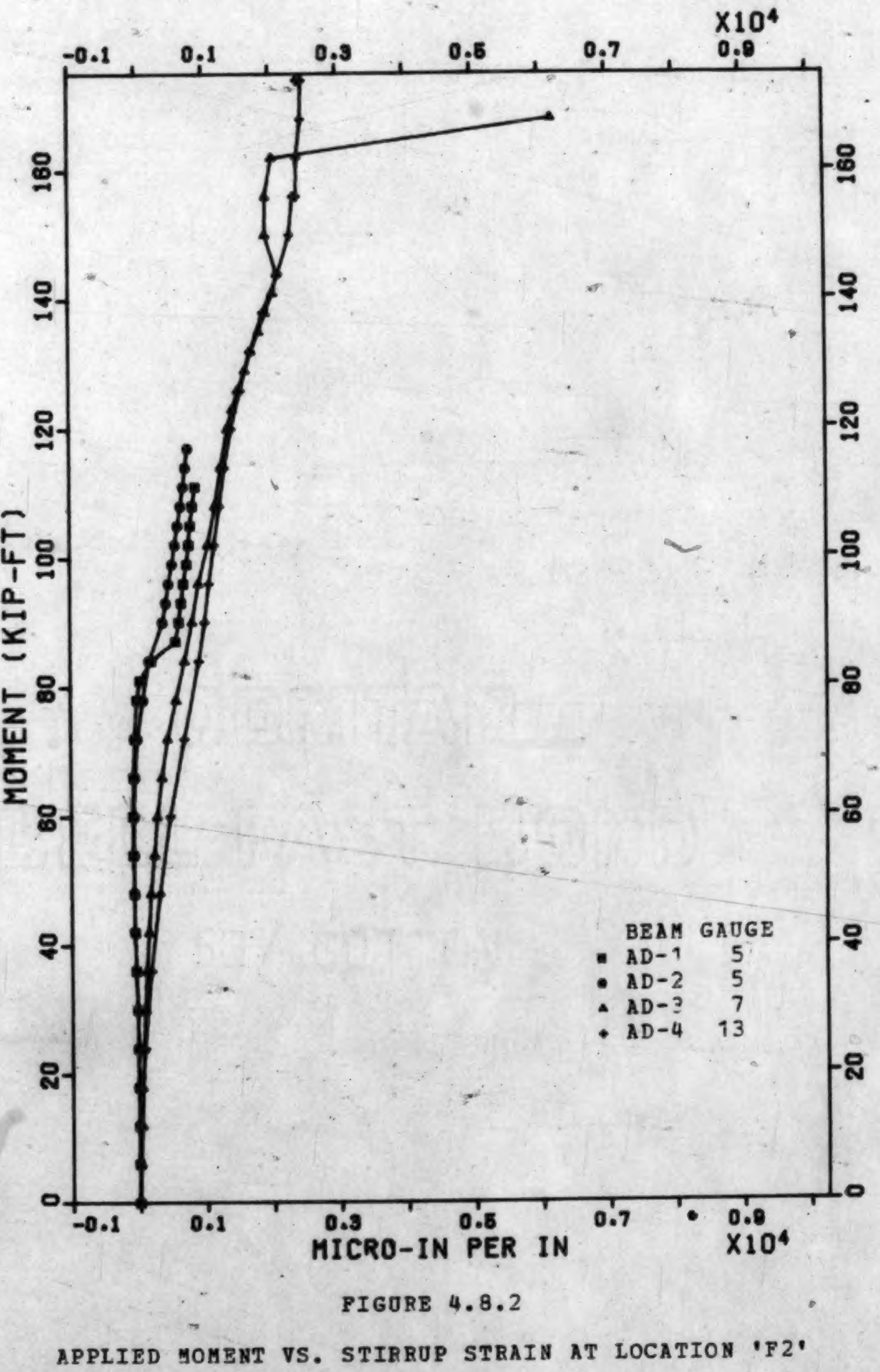


FIGURE 4.8.2

APPLIED MOMENT VS. STIRRUP STRAIN AT LOCATION 'F2'

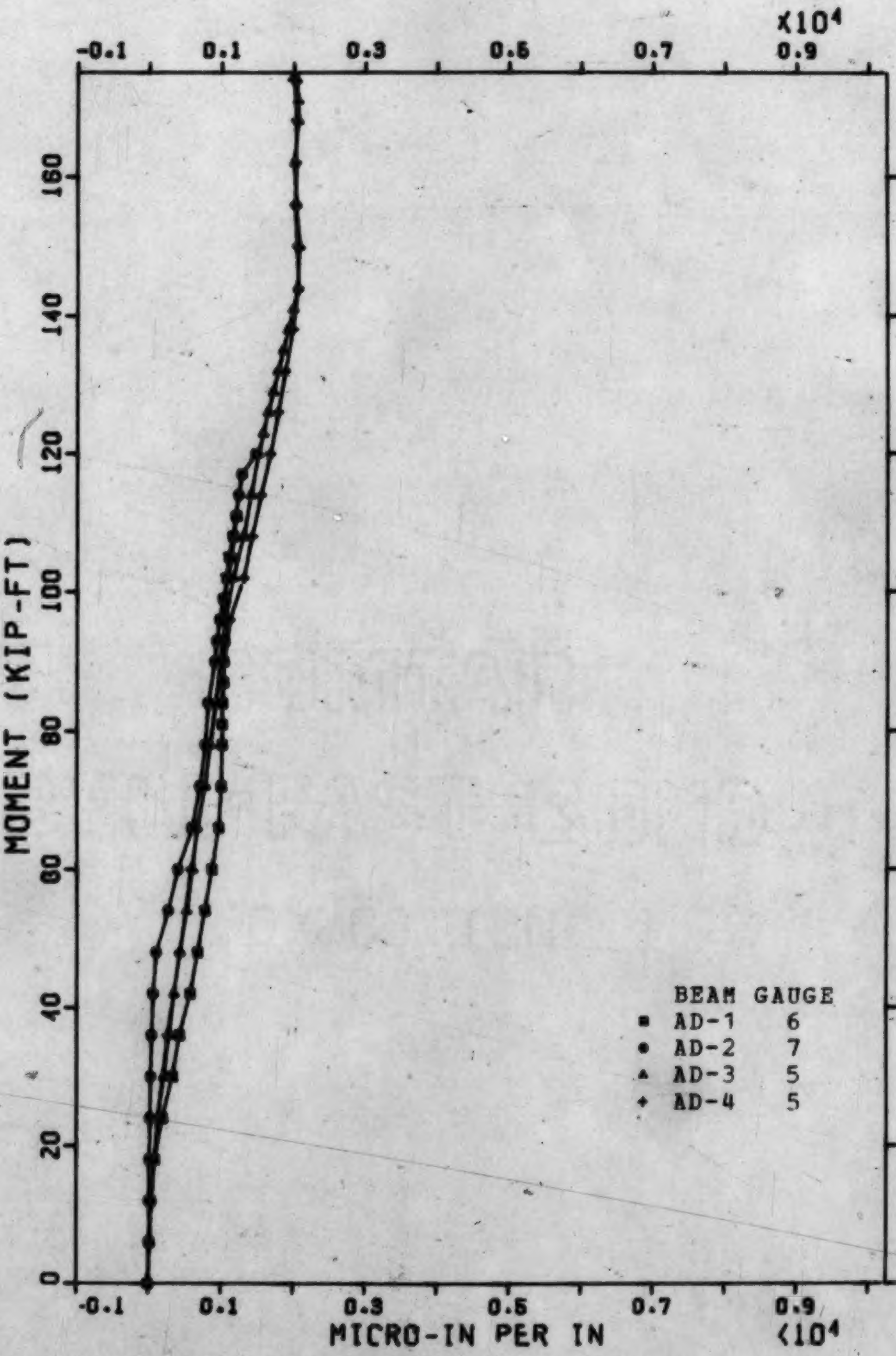


FIGURE 4.8.3

APPLIED MOMENT VS. STIRRUP STRAIN AT LOCATION 'F3'

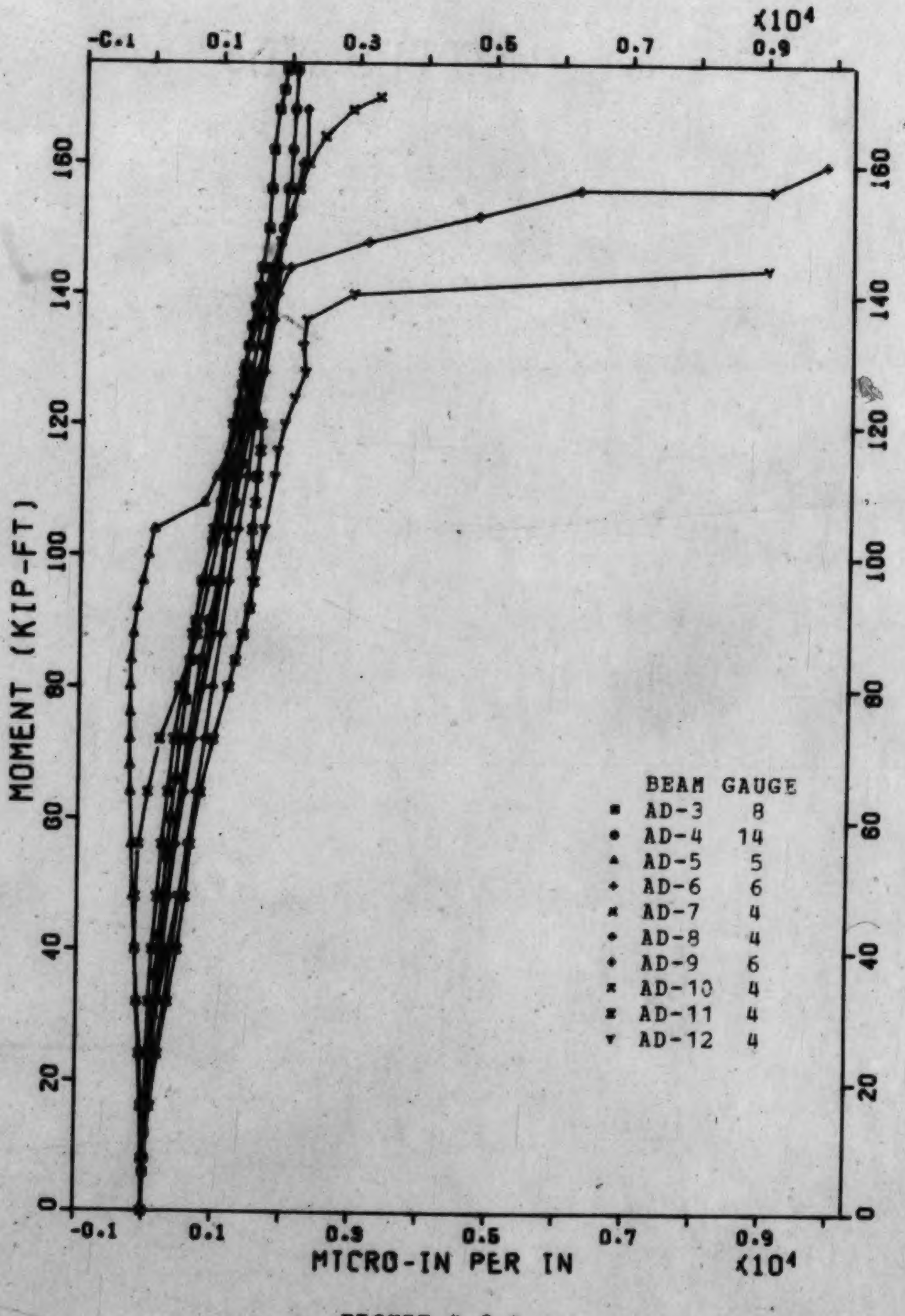


FIGURE 4.8.4

APPLIED MOMENT VS. STIRRUP STRAIN AT LOCATION 'F4'

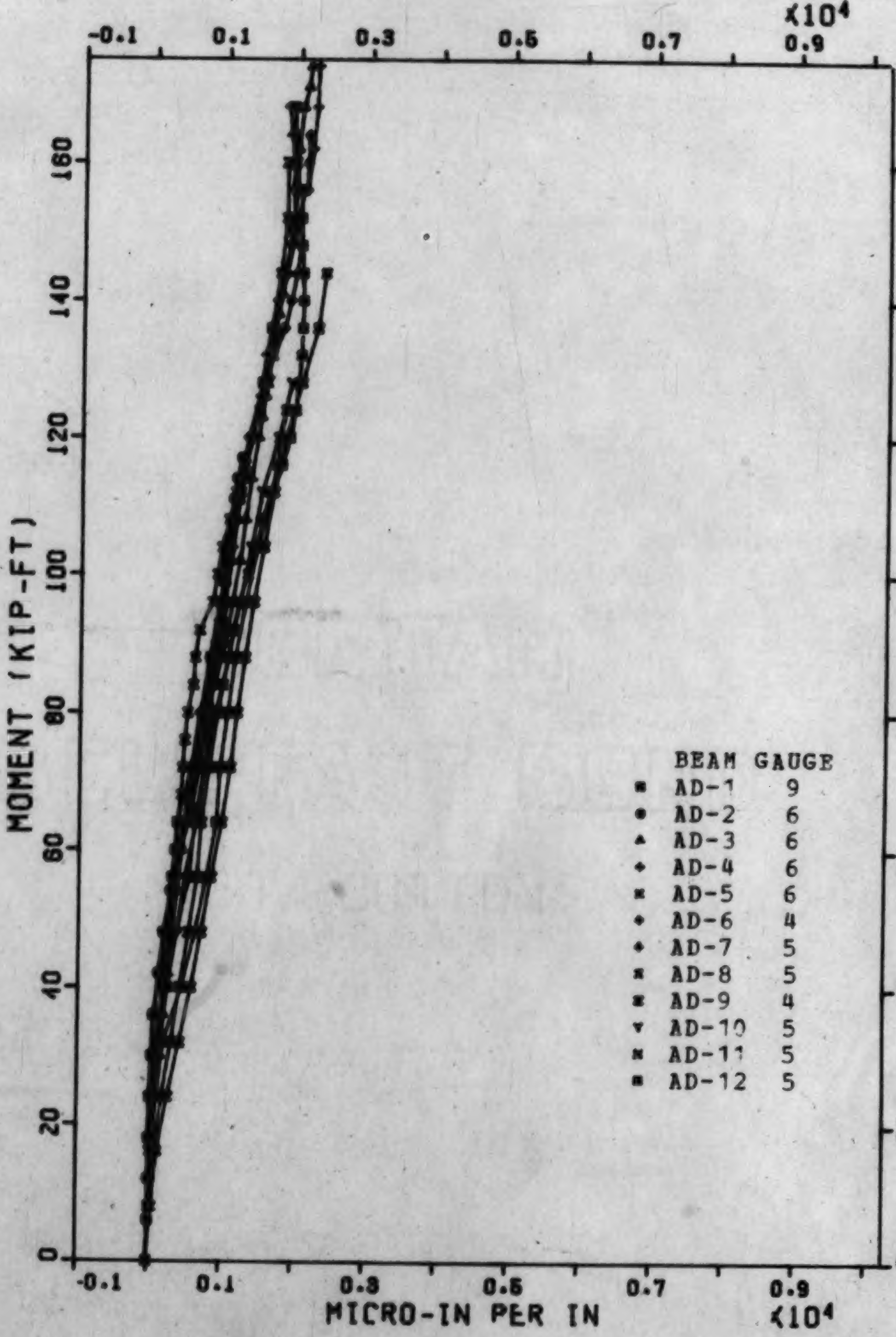


FIGURE 4.8.5

APPLIED MOMENT VS. STIRRUP STRAIN AT LOCATION 'F5'

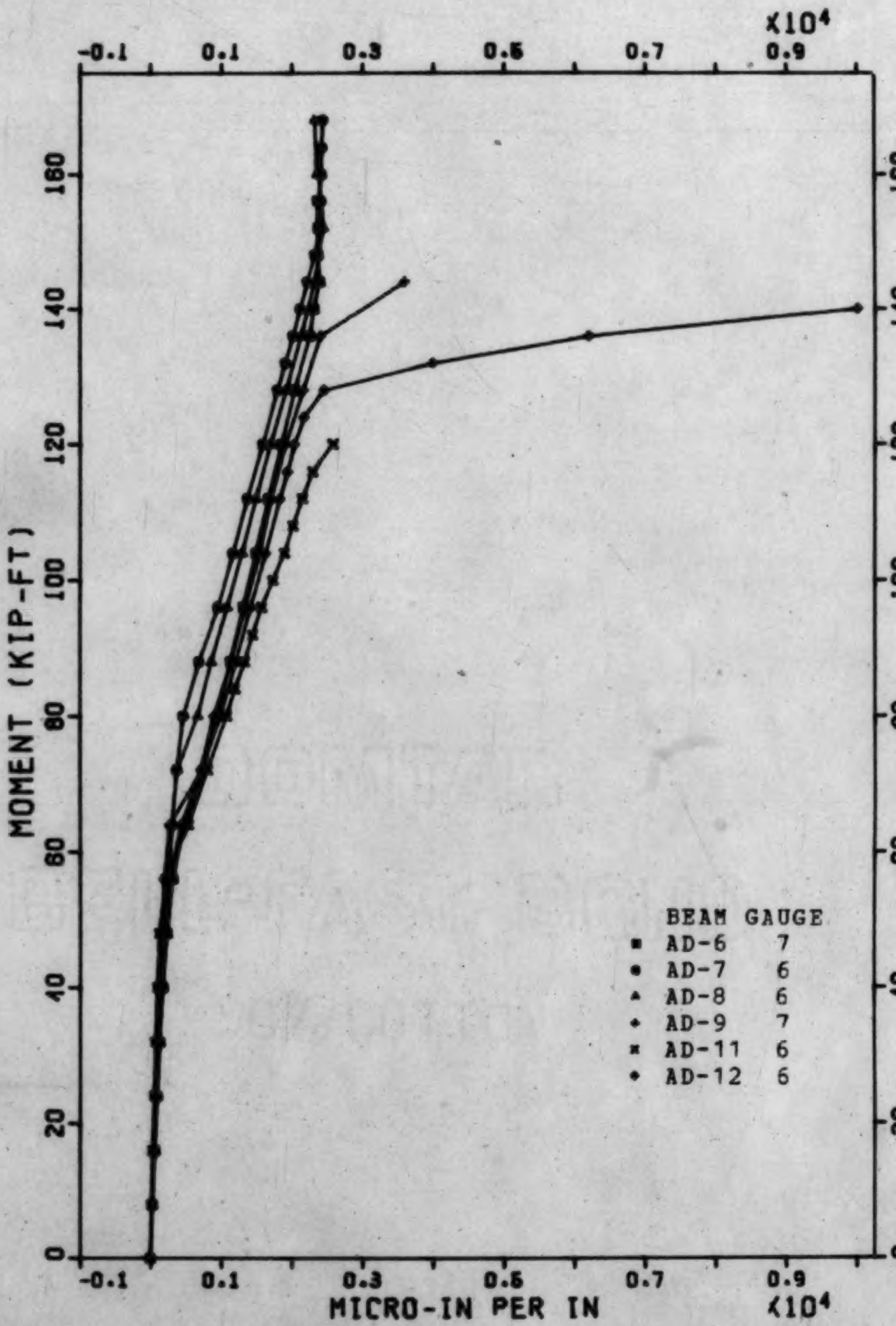


FIGURE 4.8.6

APPLIED MOMENT VS. STIRRUP STRAIN AT LOCATION 'F6'

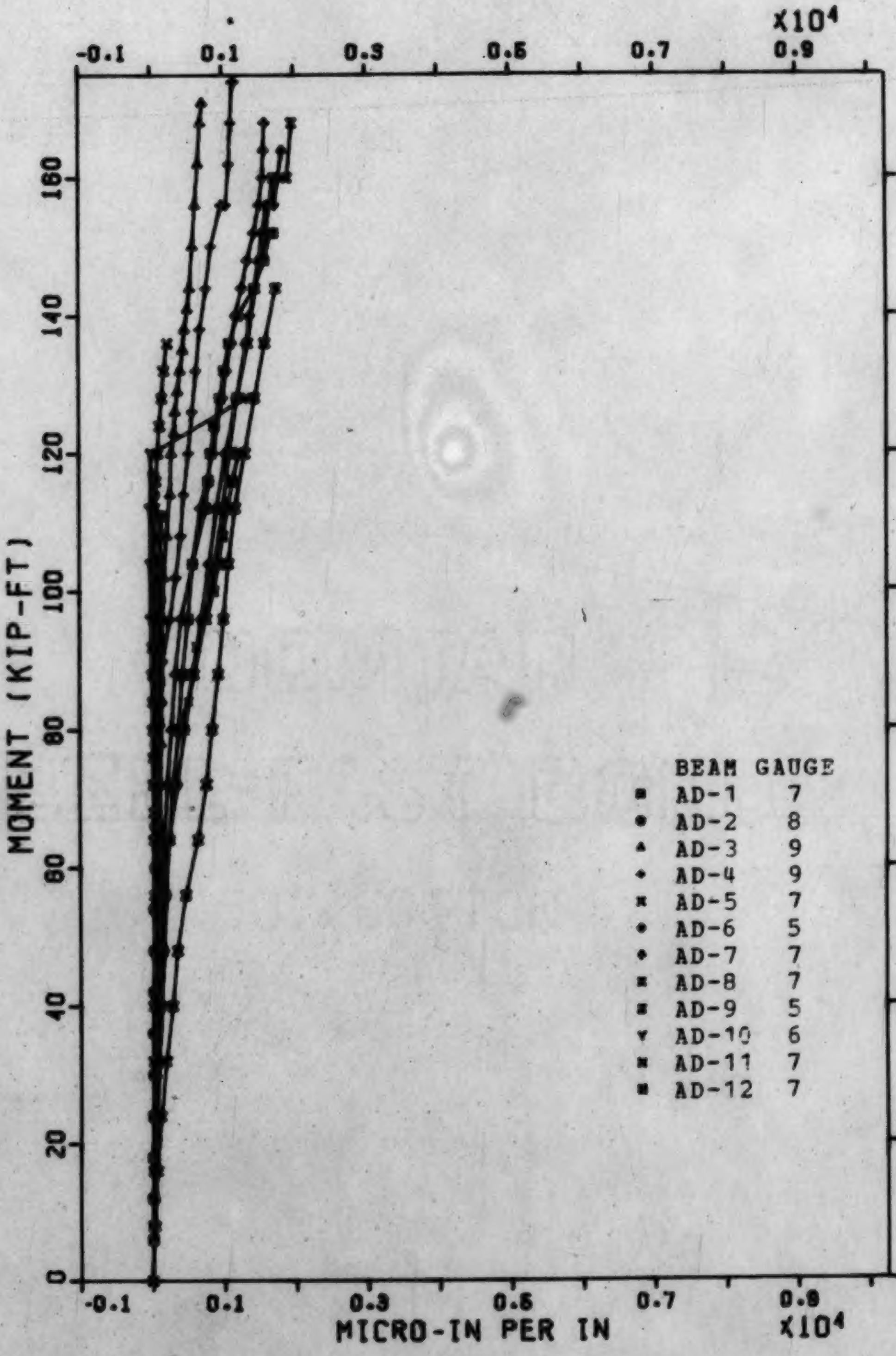


FIGURE 4.8.7

APPLIED MOMENT VS. STIRRUP STRAIN AT LOCATION 'F7'

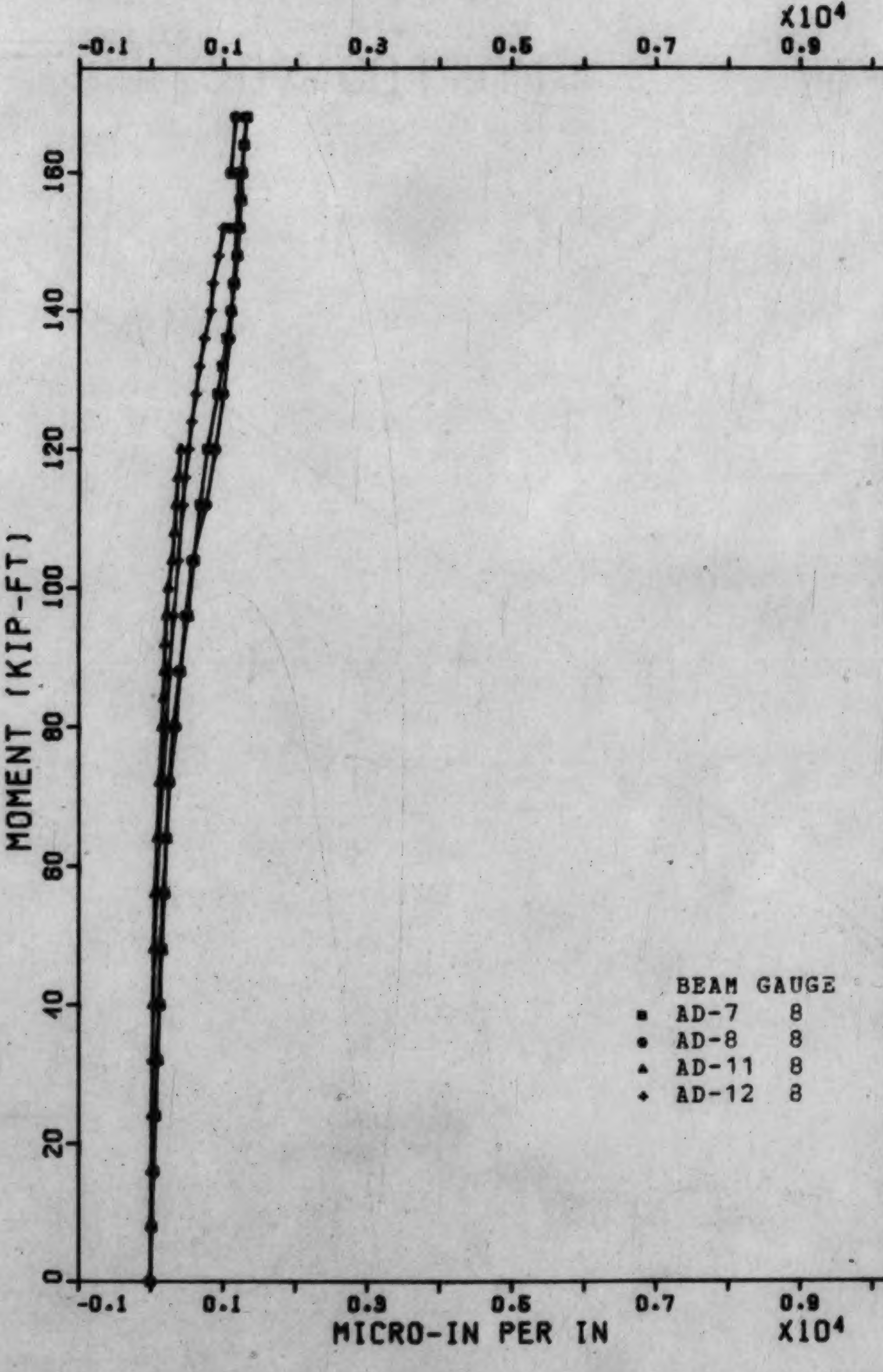


FIGURE 4.8.8

APPLIED MOMENT VS. STIRRUP STRAIN AT LOCATION 'F8'

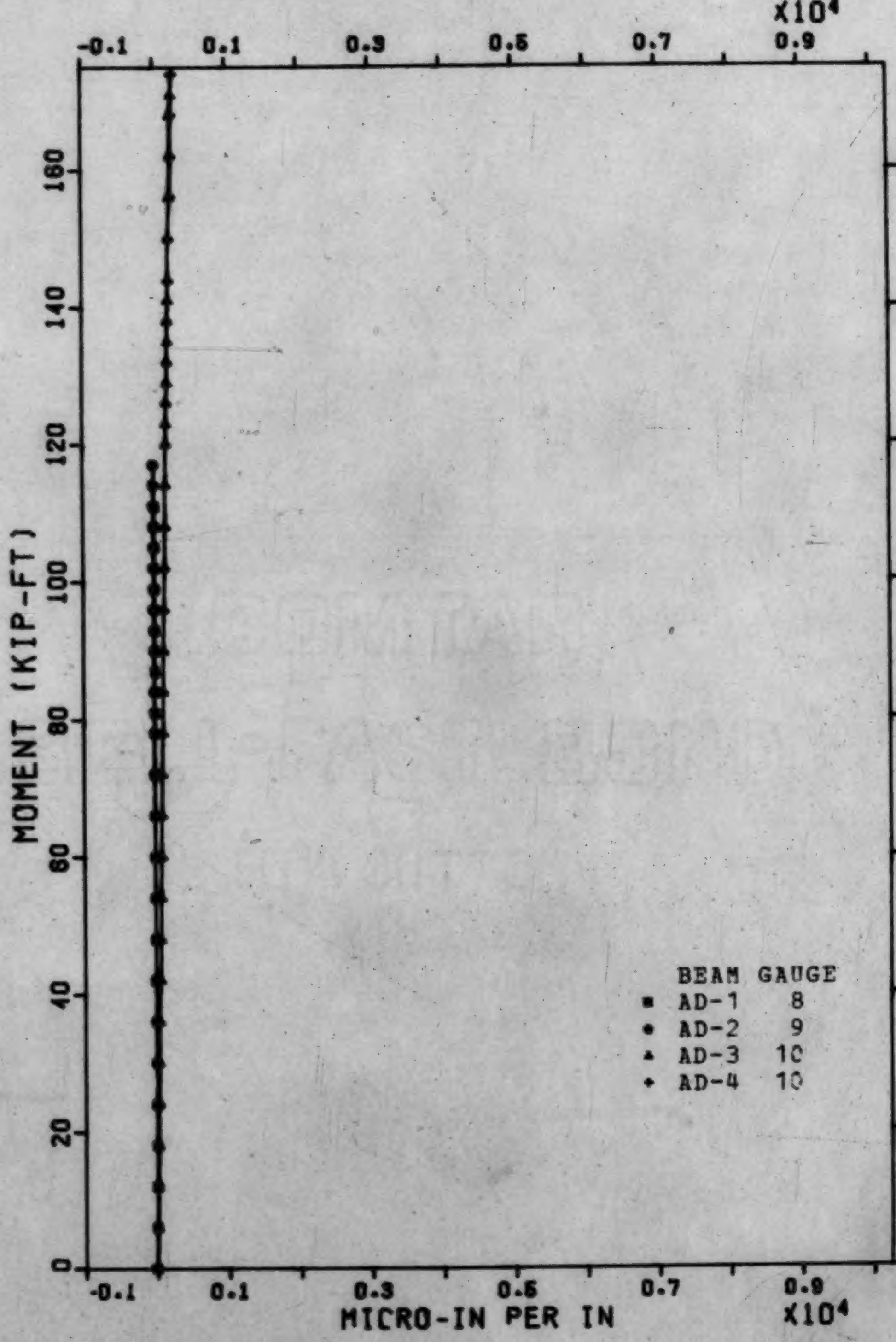


FIGURE 4.8.9

APPLIED MOMENT VS. STIRRUP STRAIN AT LOCATION 'F9'

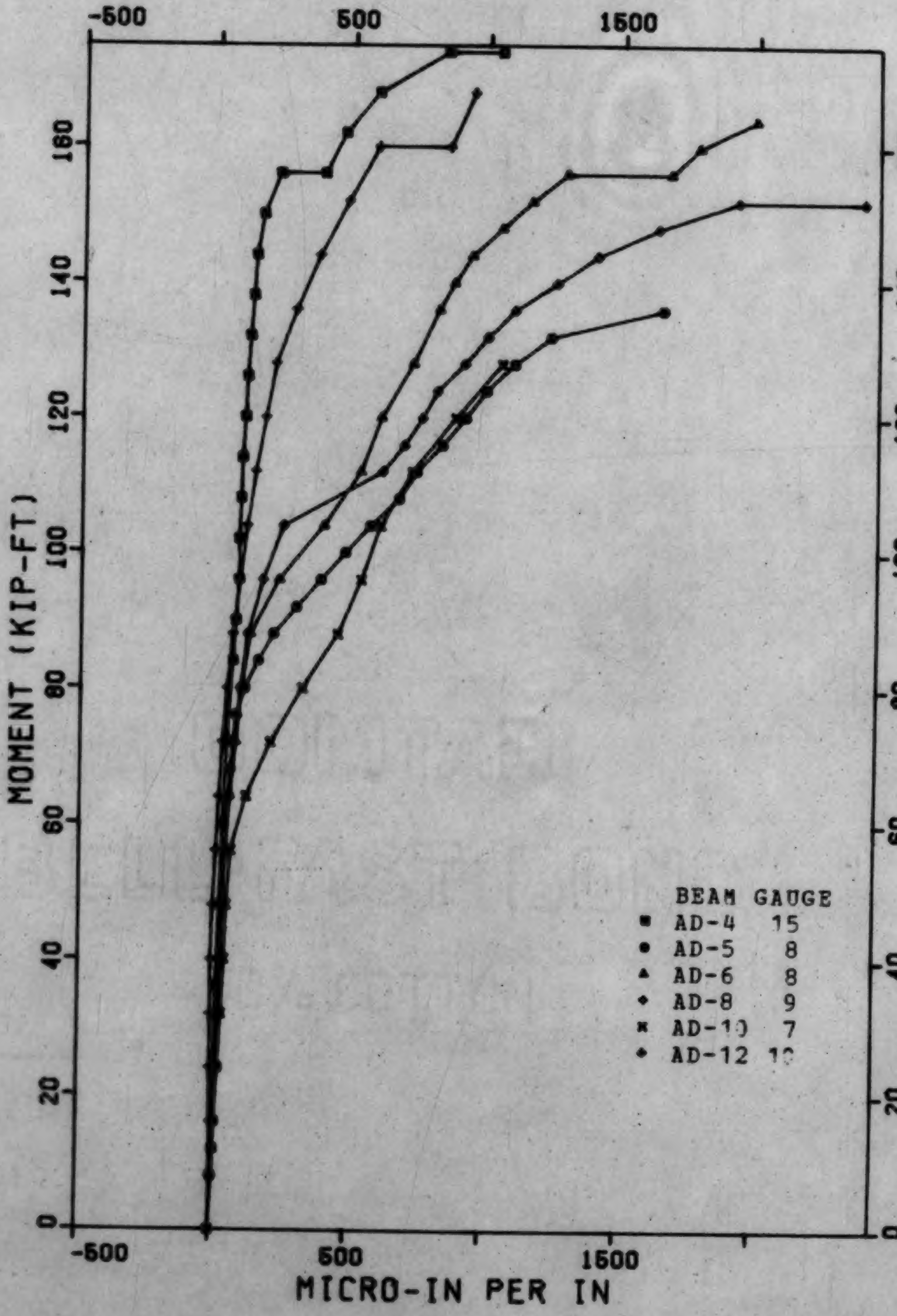


FIGURE 4.9.1 UPPER WEB STIRRUPS

APPLIED MOMENT VS. MOST CRITICAL STRAINS

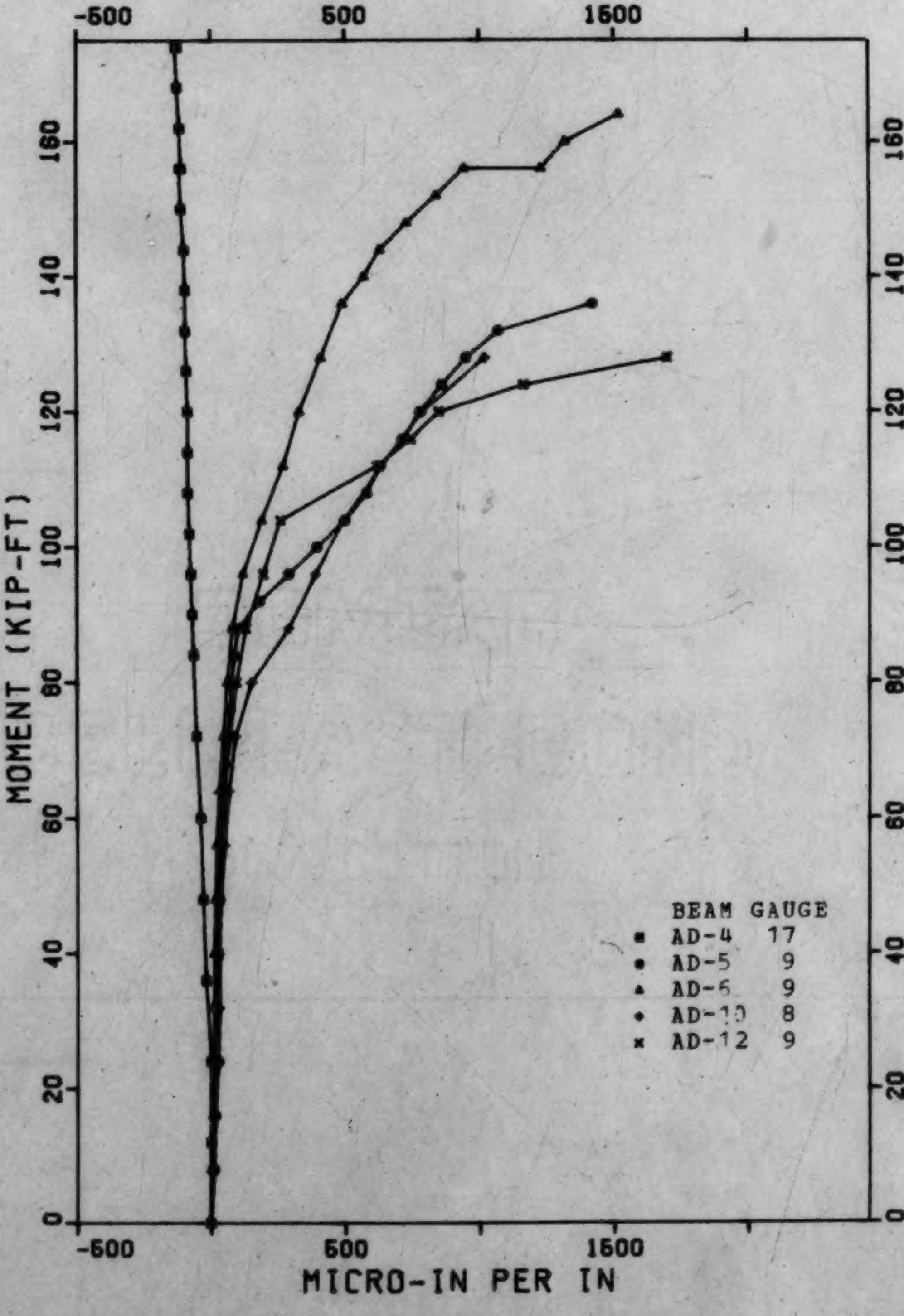


FIGURE 4.9.2 UPPER WEB STIRRUPS

APPLIED MOMENT VS. INTERMEDIATE STRAINS

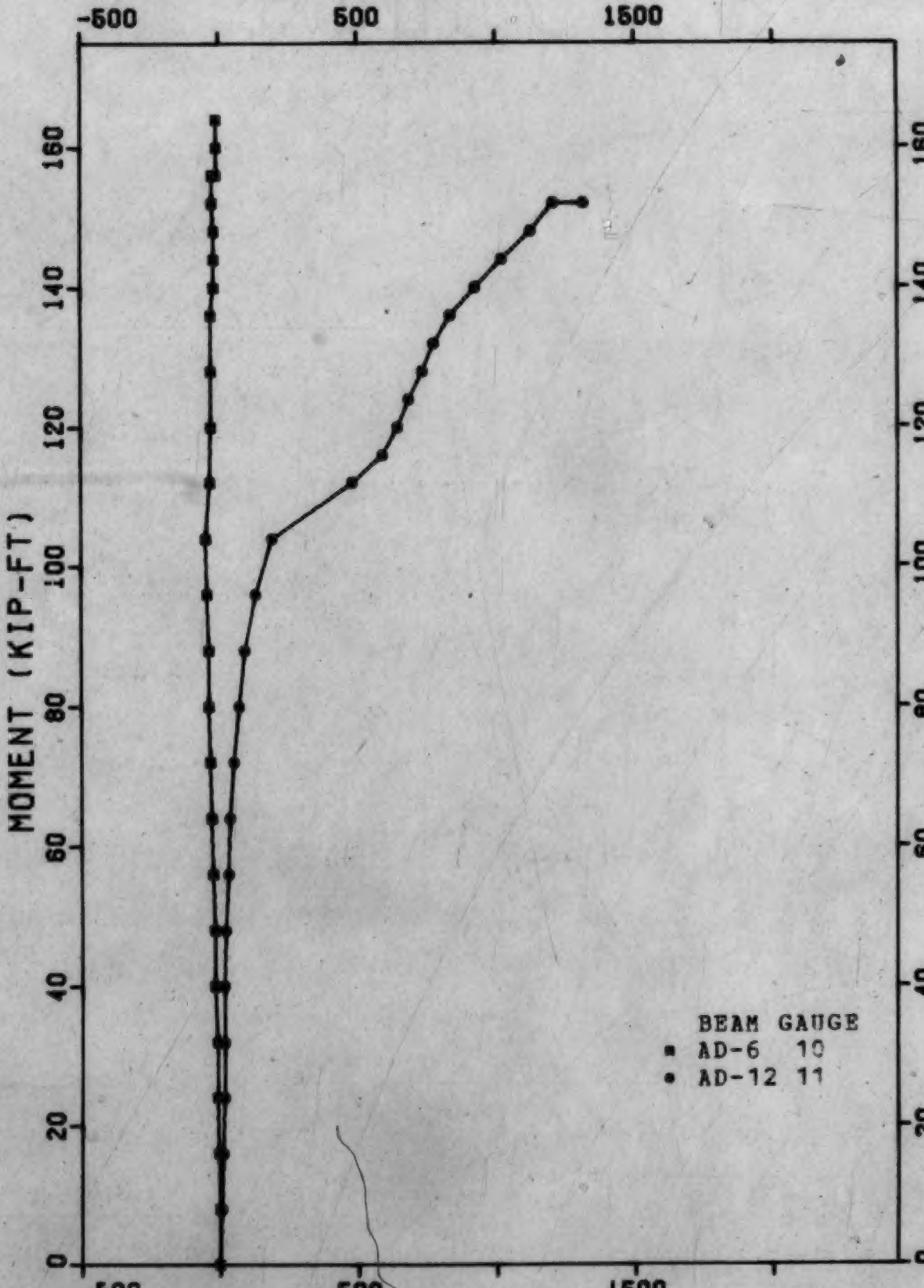


FIGURE 4.9.3 UPPER WEB STIRRUPS

APPLIED MOMENT VS. LEAST CRITICAL STRAINS

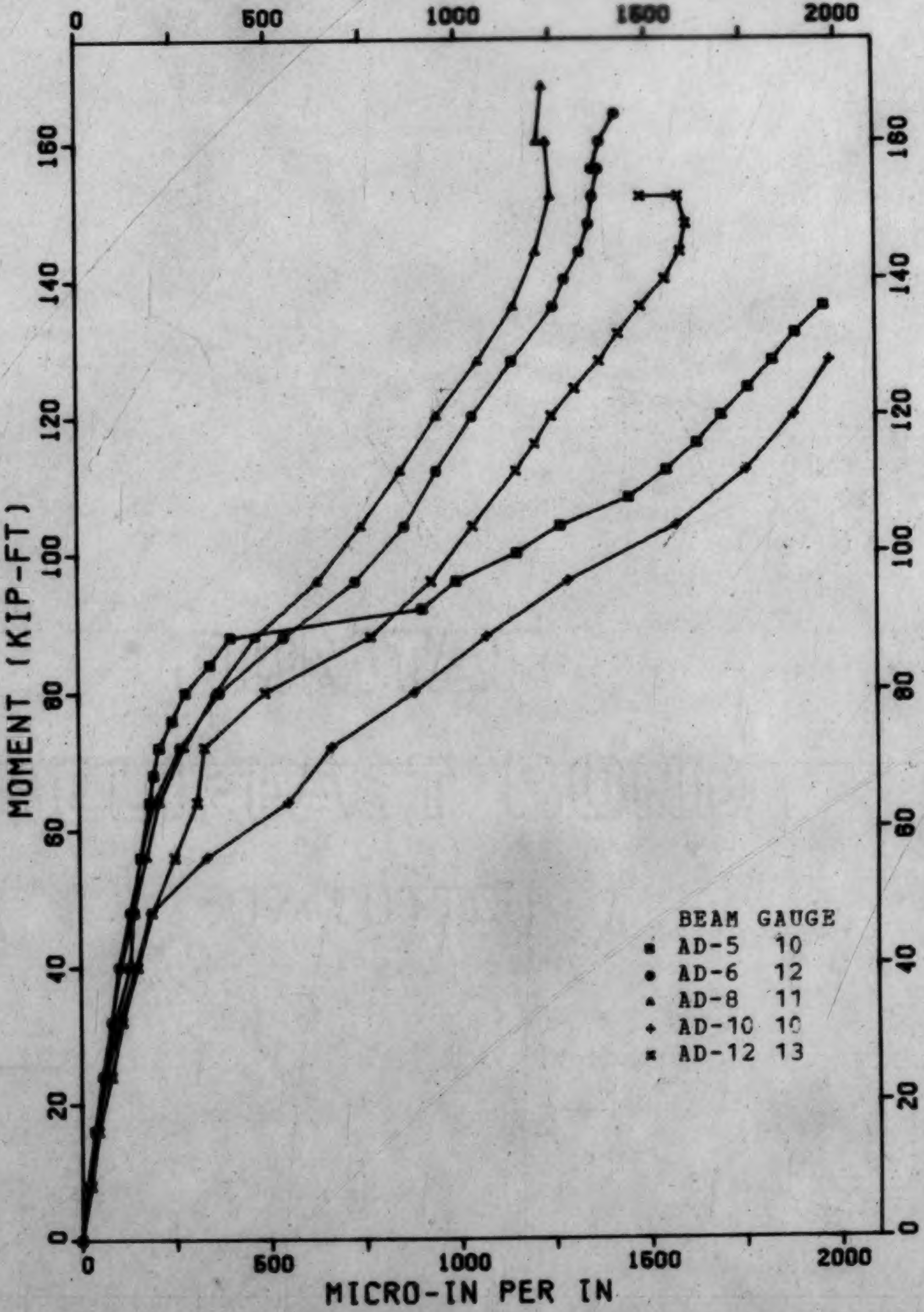


FIGURE 4.10.1 LOWER WEB STIRRUPS

APPLIED MOMENT VS. MOST CRITICAL STRAINS

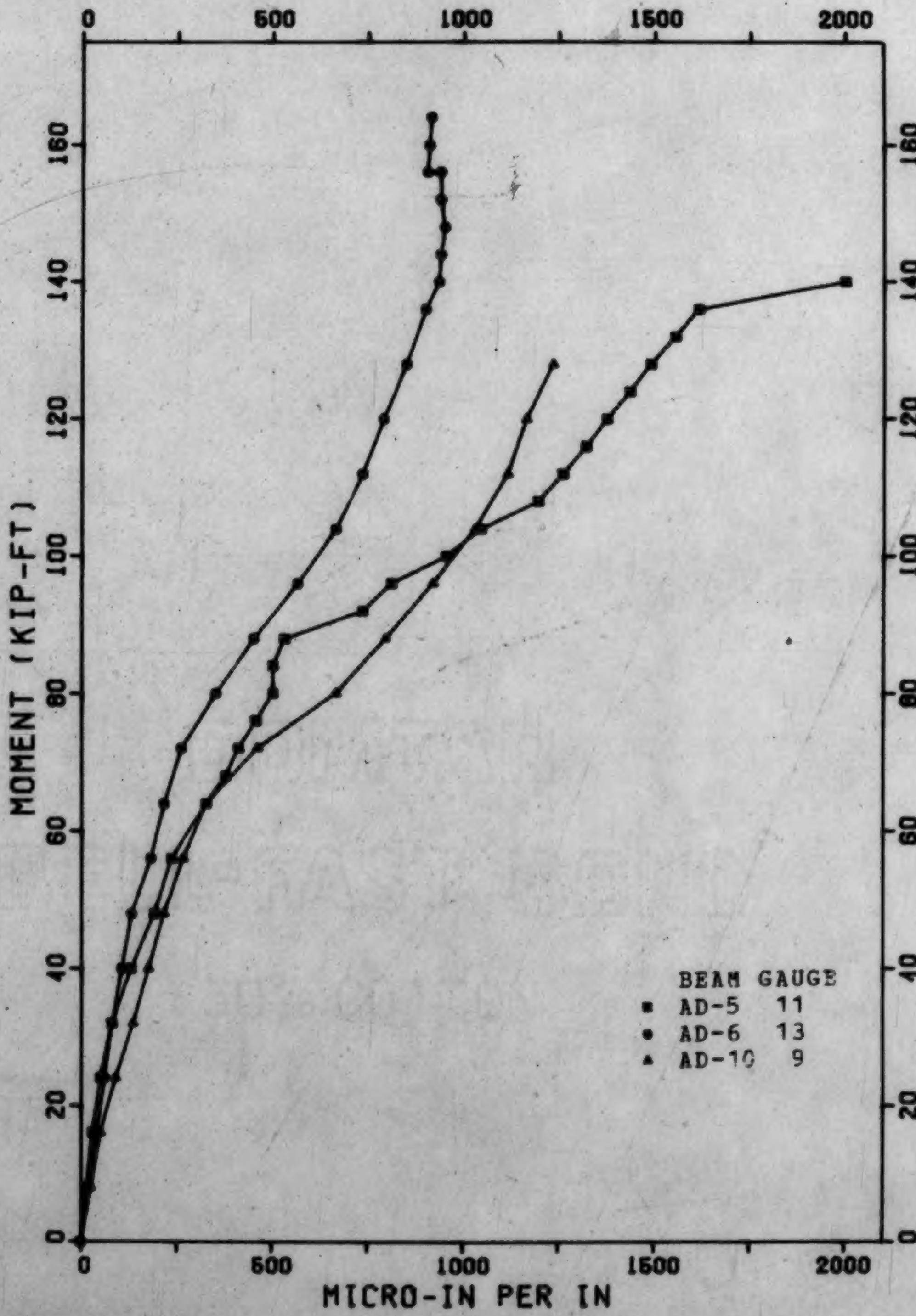


FIGURE 4.10.2 LOWER WEB STIRRUPS

APPLIED MOMENT VS. INTERMEDIATE STRAINS

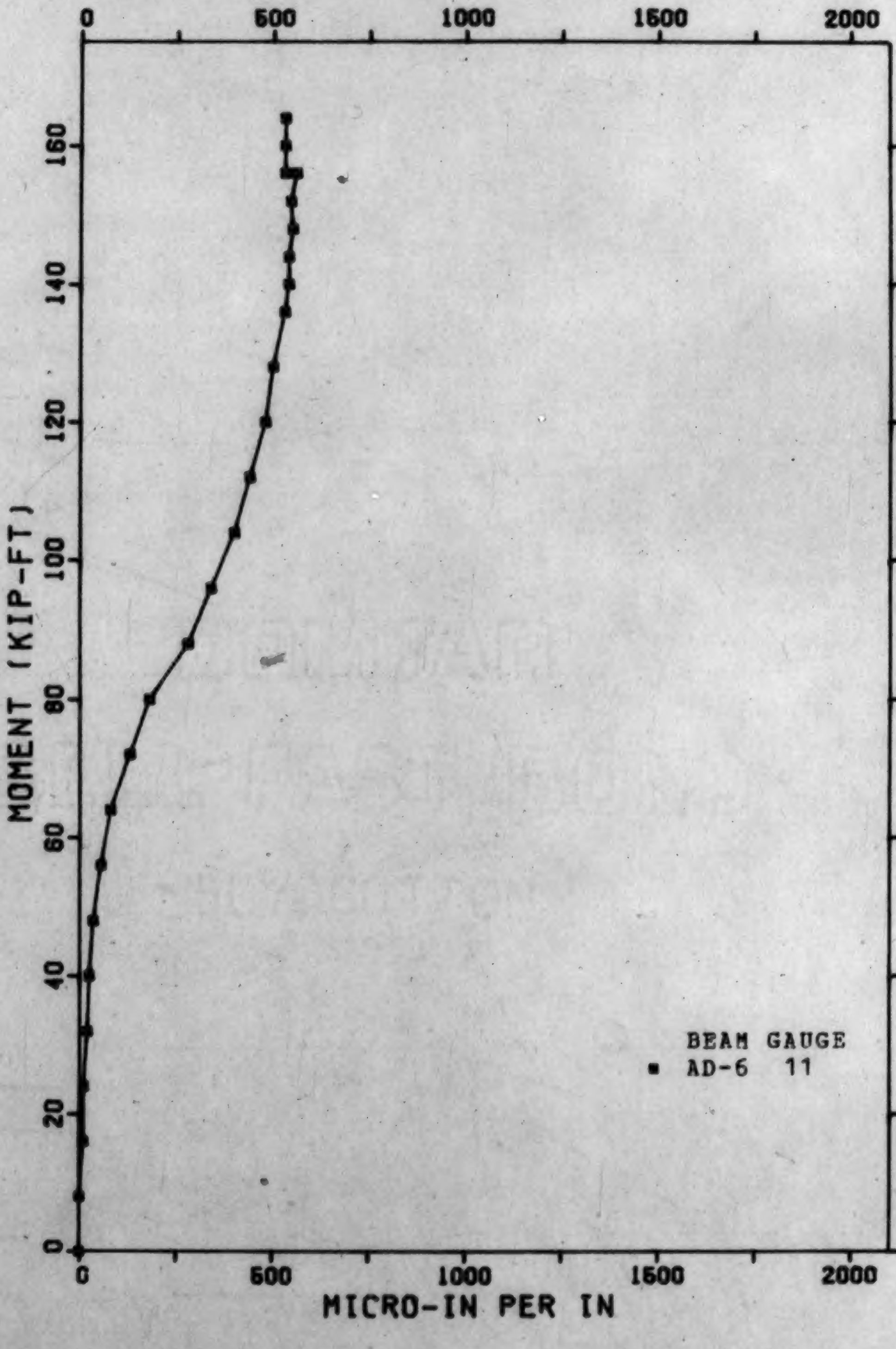


FIGURE 4.10.3 LOWER WEB STIRRUPS

APPLIED MOMENT VS. LEAST CRITICAL STRAINS

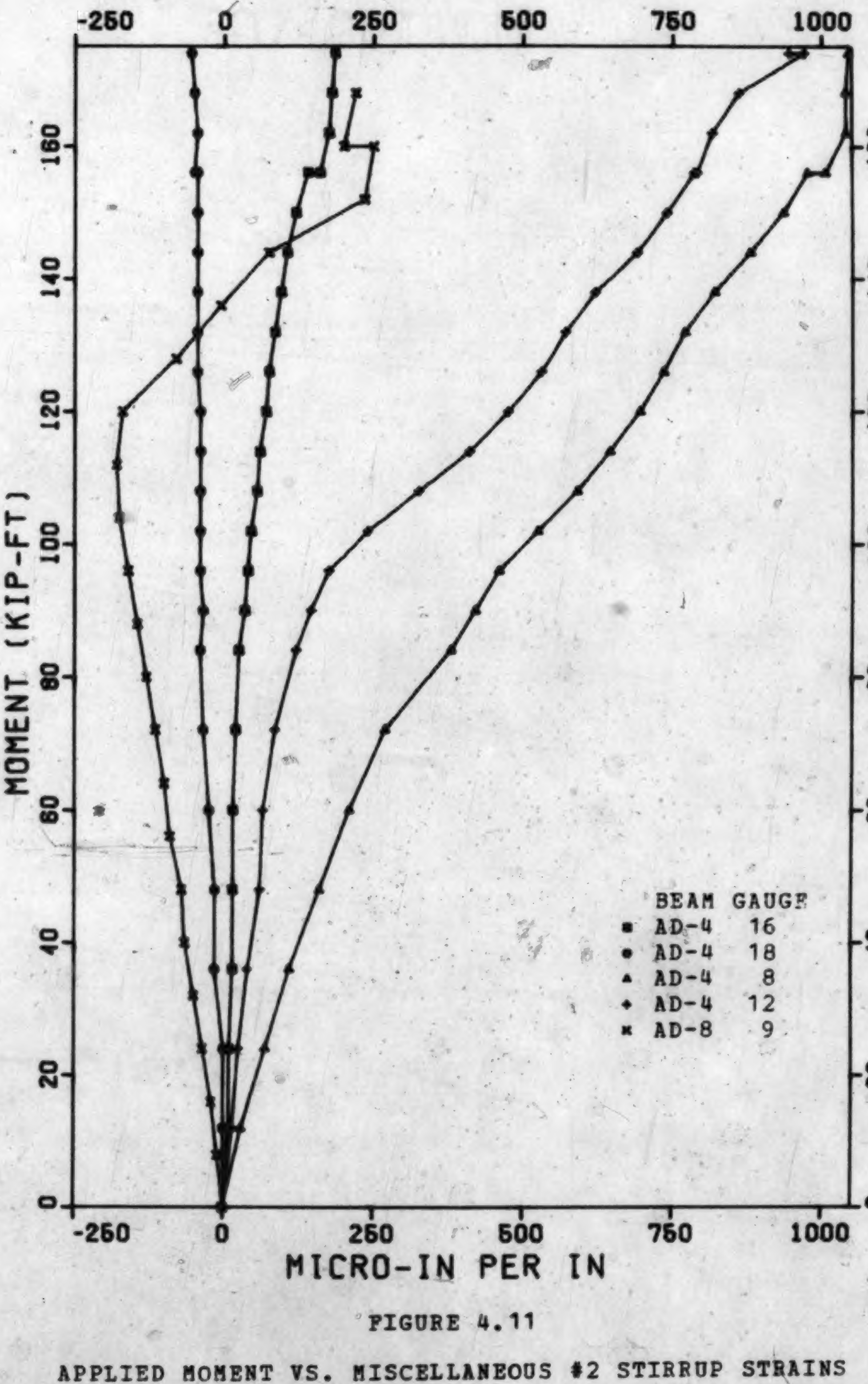


FIGURE 4.11

APPLIED MOMENT VS. MISCELLANEOUS #2 STIRRUP STRAINS

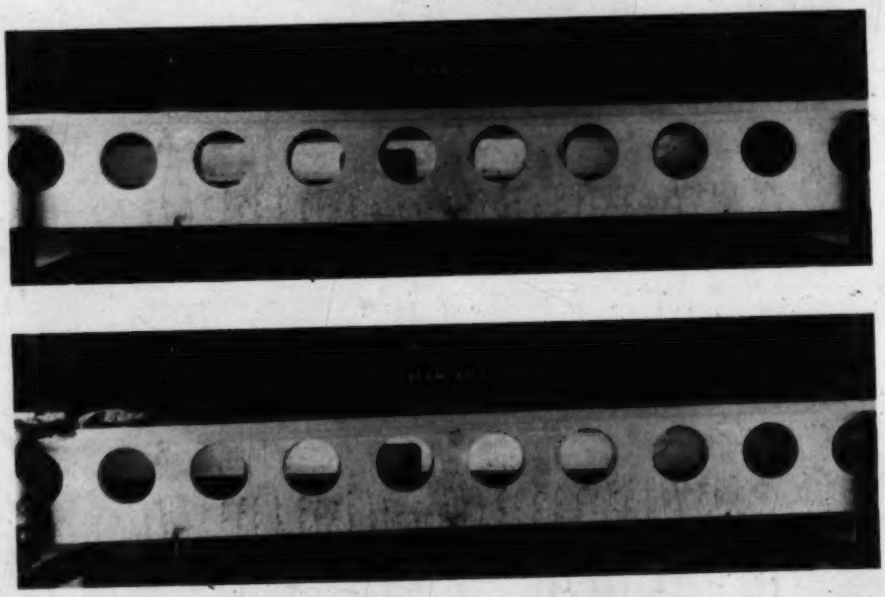


PLATE 4.1 BEAM AD-1 CRACKING AND FAILURE PATTERNS

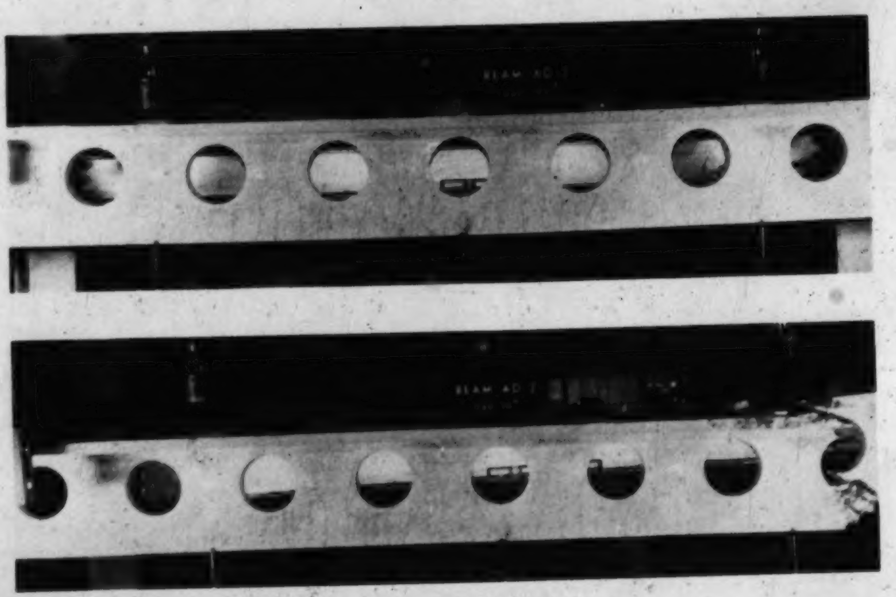


PLATE 4.2 BEAM AD-2 CRACKING AND FAILURE PATTERNS

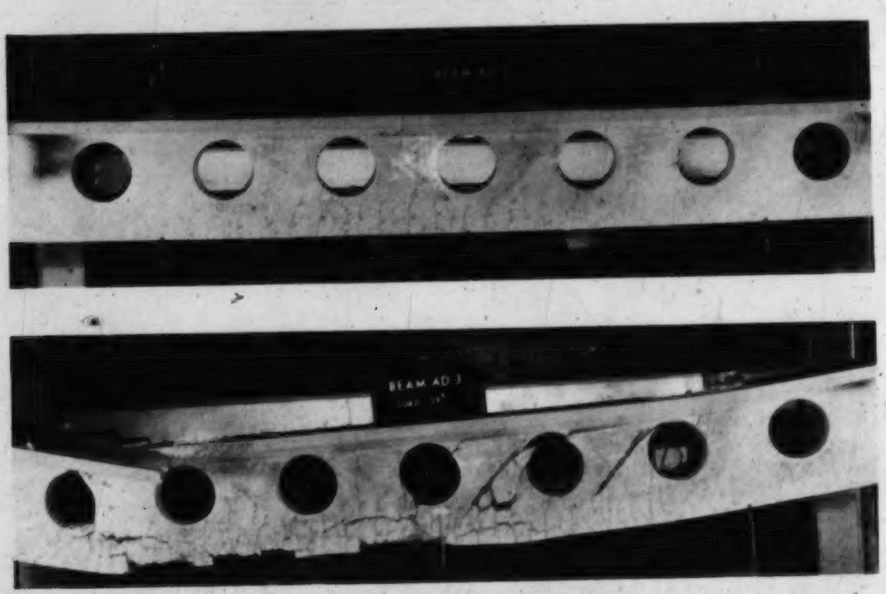


PLATE 4.3 BEAM AD-3 CRACKING AND FAILURE PATTERNS

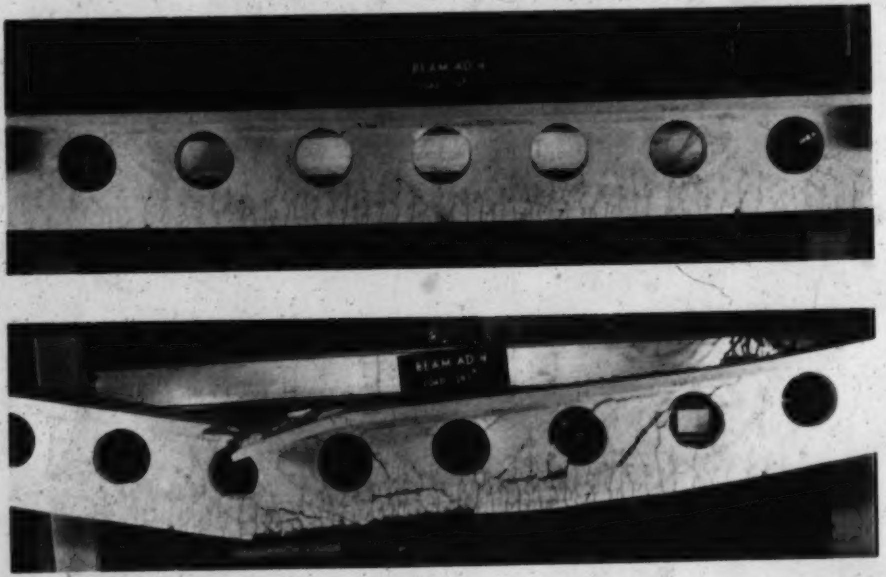


PLATE 4.4 BEAM AD-4 CRACKING AND FAILURE PATTERNS

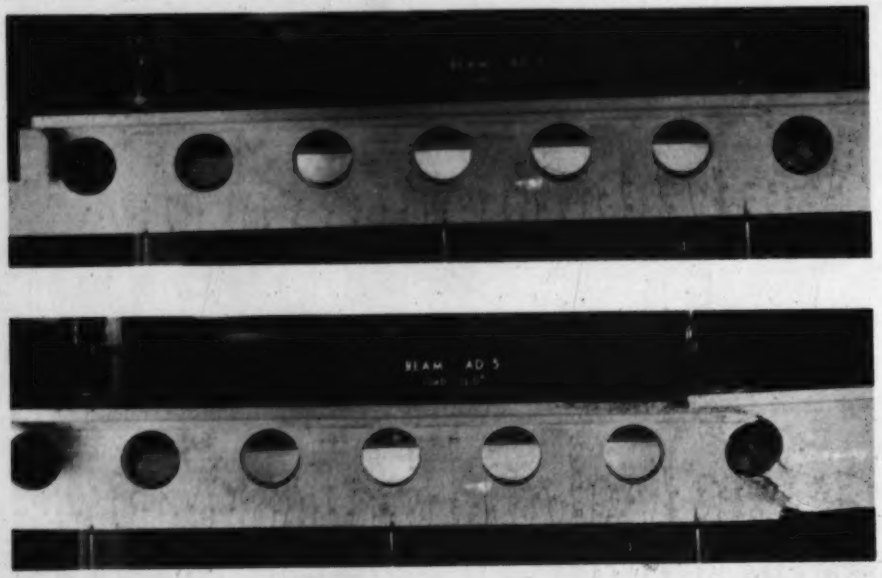


PLATE 4.5 BEAM AD-5 CRACKING AND FAILURE PATTERNS

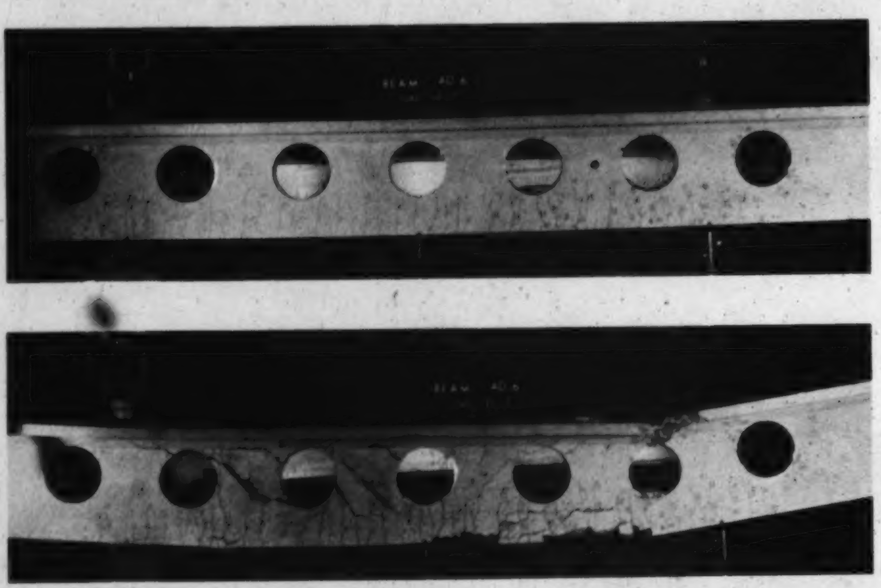


PLATE 4.6 BEAM AD-6 CRACKING AND FAILURE PATTERNS

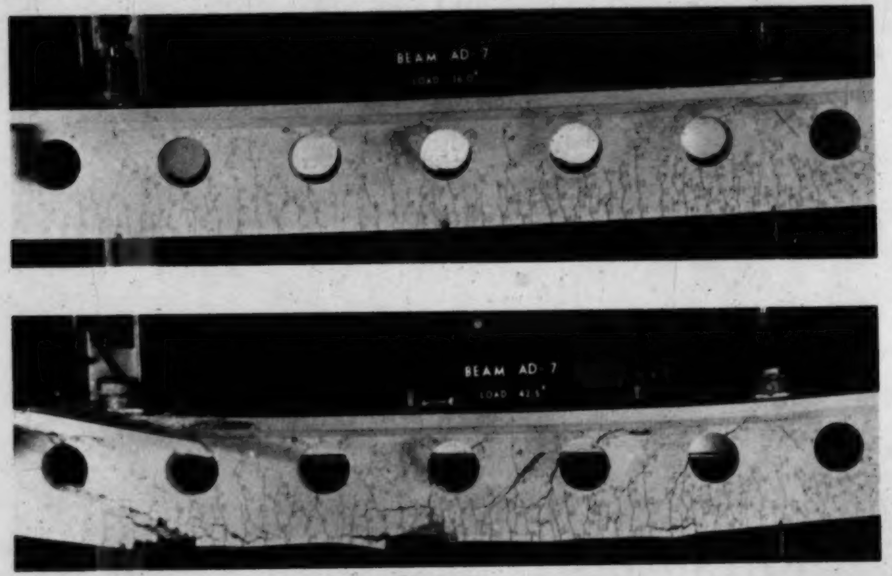

BEAM AD-7
LOAD 16.0k
BEAM AD-7
LOAD 42.5k

PLATE 4.7 BEAM AD-7 CRACKING AND FAILURE PATTERNS

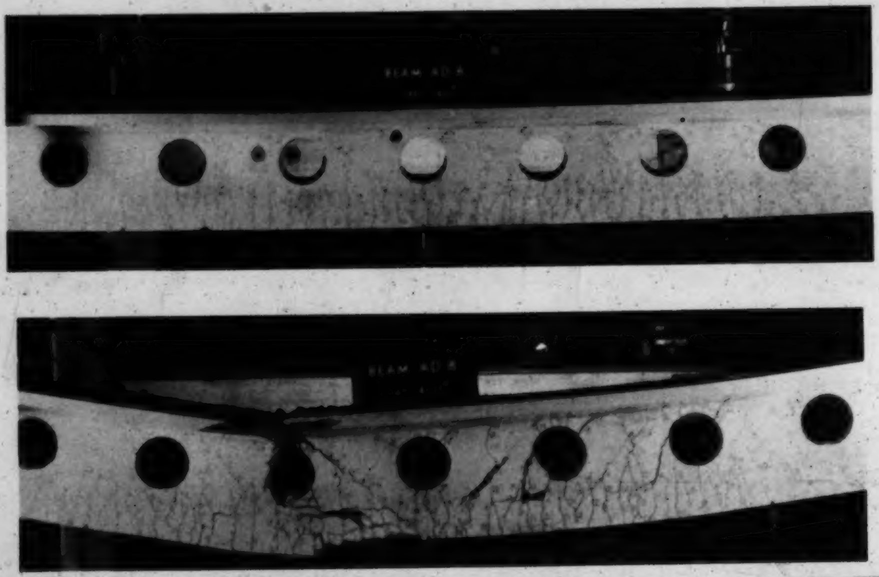

BEAM AD-8
BEAM AD-8

PLATE 4.8 BEAM AD-8 CRACKING AND FAILURE PATTERNS

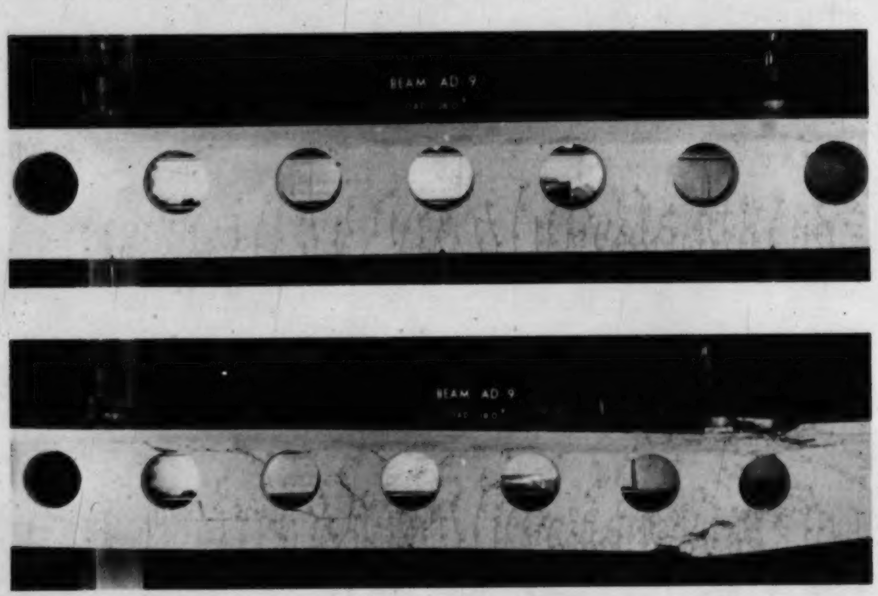

BEAM AD 9
BEAM AD 9

PLATE 4.9 BEAM AD-9 CRACKING AND FAILURE PATTERNS

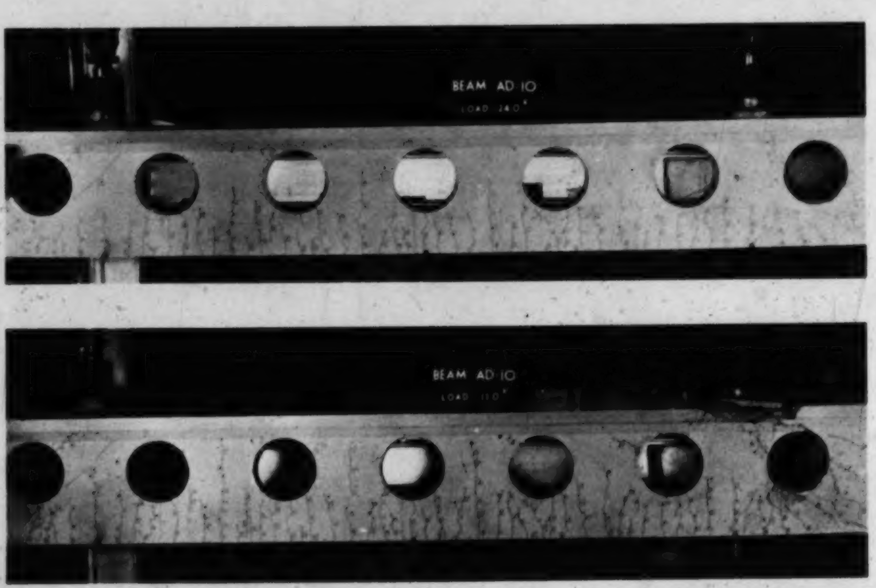

BEAM AD 10
LOAD 24.0 k
BEAM AD 10
LOAD 11.0 k

PLATE 4.10 BEAM AD-10 CRACKING AND FAILURE PATTERNS

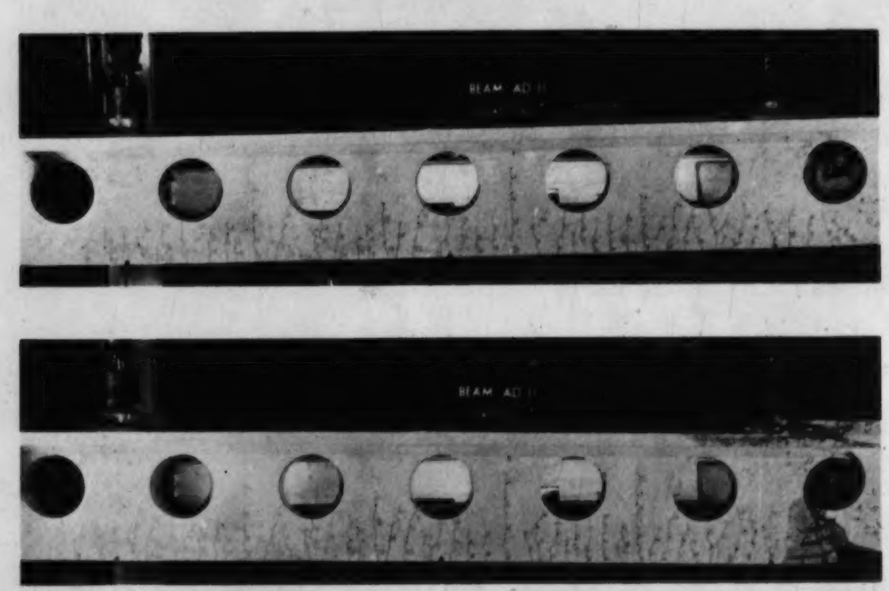

BEAM AD 11
BEAM AD 11

PLATE 4.11 BEAM AD-11 CRACKING AND FAILURE PATTERNS

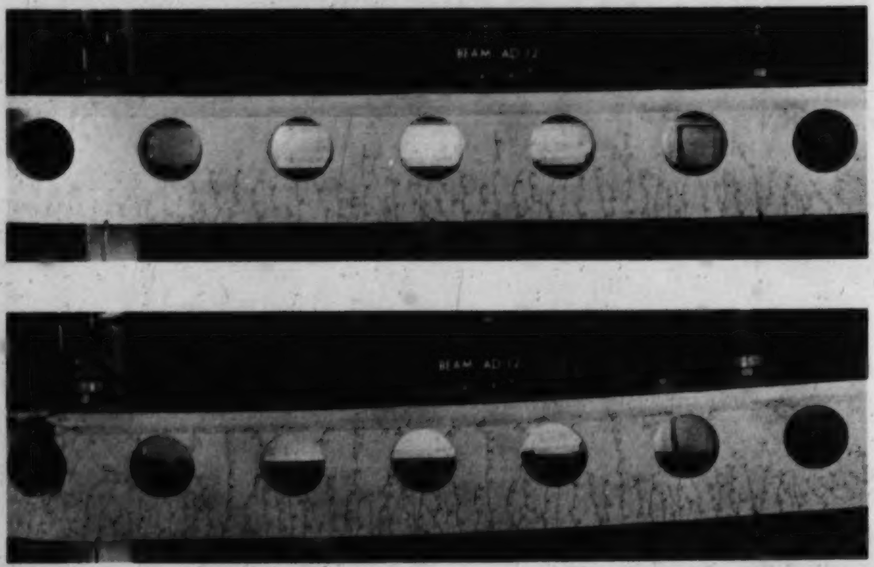

BEAM AD 12
BEAM AD 12

PLATE 4.12 BEAM AD-12 CRACKING AND FAILURE PATTERNS

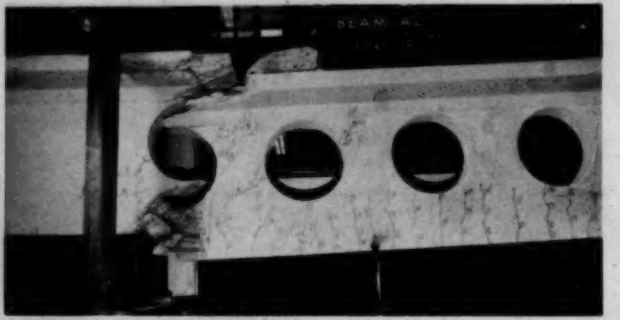


PLATE 4.13 BEAM AD-1

TYPICAL SHEAR FAILURE DETAIL

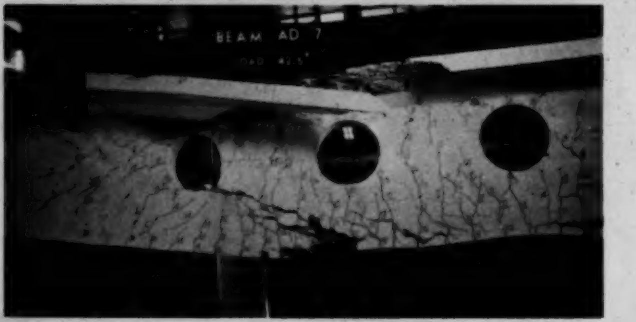


PLATE 4.14 BEAM AD-7

TYPICAL SHEAR-COMPRESSION FAILURE DETAIL

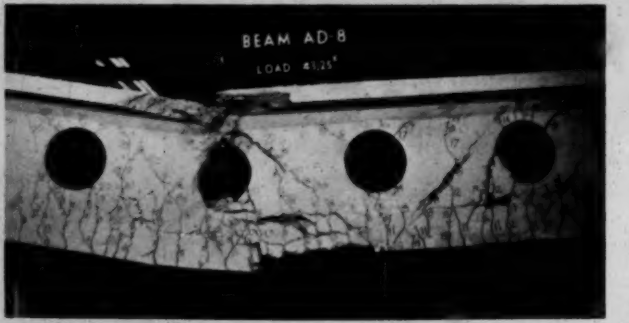

BEAM AD-8
LOAD 41.25K

PLATE 4.15 BEAM AD-8

TYPICAL FLEXURAL FAILURE DETAIL

CHAPTER V

DISCUSSION

The test series reported herein consisted of twelve prestressed concrete tee beams, each containing circular web openings. The principal variables included were arrangement of shear reinforcement and loading configuration, while variables of secondary concern were hole size and spacing. The following discussion, supplemented by the figures in Chapters III and IV, describes the behaviour of the beams under load and relates it to the variables mentioned above.

5.1 Parameters

In all cases two equal point loads were positioned symmetrically at either four or six feet from the supports. Thus to reach the ultimate moment capacity of the section, two different severities of shear stress would also be developed. Because no failure mechanisms were formed involving more than one hole, the presence of an extra hole in the longer shear spans of the first four beams had little influence on behaviour and was not considered as a variable.

Ten inch diameter holes were spaced at 20 inches on centre in all beams except AD-1, in which a 16 inch spacing was used. This beam failed at 19 kips whereas AD-2, similar in all respects but hole spacing, failed at 20 kips. The difference is not large enough to attribute it solely to the difference in spacing, particularly considering the higher measured compressive and tensile strengths of the concrete of AD-2.

The inclusion in the series of beams AD-7 and AD-8, containing the smaller 8 inch diameter holes, did little to isolate the effects of hole size on shear strength as they both had more stirrups per post than other beams. These two beams failed at or near flexural capacity, making it difficult to determine their actual shear strength. The failure at or near flexural capacity of AD-6 and AD-9, the beams most similar to AD-7 and AD-8, also made the combined strengthening effect of smaller holes and more stirrups difficult to assess. It is intuitively obvious, however, that smaller holes in the shear span will decrease the possibility of shear failure, by removing less concrete, and by providing more room for shear reinforcement.

The variations of shear reinforcement formed the most important parameter of these tests. Initial calculations for shear reinforcement requirements ignoring the holes showed that vertical #3 stirrups could be placed in the longer shear spans at 15 inches, and in the shorter shear spans at 10 inches. As well as weakening the beams, the presence of the web openings placed restrictions on possible stirrup locations. While the average spacing of stirrups in the first four beams was 8 or 10 inches, the distance between two stirrups surrounding a hole was 12 or

17 inches depending on their slope.

Full-depth #3 "U" stirrups, as shown in Figure 3.3, were employed in all beams as the primary shear reinforcement. They were fabricated in different heights to allow their placement at 90°, 60°, or 45° to the longitudinal beam axis. In the case of beams AD-7 and AD-8, stirrups of twice the area were produced by tack welding two regular stirrups together.

Secondary shear reinforcement was also provided in six beams in the form of closed #2 stirrups above and below holes in critical shear regions. They were modeled after those of Linder, who developed them pursuant to the recommendations of Le Blanc. Because of the small web depths available, especially for the upper stirrups, they were all placed at 45° to take advantage of the resulting efficiency and overlapping effect of inclined stirrups.

5.2 Cracking

Besides mode of failure, the progression of cracking through loading history is an aspect of beam behaviour that is affected by the presence of web openings. The first cracks noticeable in each of the beams were a form of web shear crack extending from a shear hole in two opposite directions along a 45° line. This cracking developed at lower loads than web shear cracking in the unperforated portions of the shear spans because of the higher average diagonal tension stress across the line of the cracks caused by the presence of the holes. The next to appear were the first flexural cracks, progressing upwards from the bottom surface of the web near the load points. The total of superimposed and dead load moments at which this occurred ranged from about 640 inch-kips to 900 inch-kips, while the calculated cracking moment, based on the modulus of rupture, was about 870 inch-kips. Within a short time of its appearance the flexural cracking pattern had developed a uniform density and crack length, both of which increased with successive loading until the concrete in the lower webs became unable to contribute to lower web tensile strength. A similar series of flexure-shear cracks also developed in the shear spans, curving upwards and away from the beam ends.

As the neutral axis migrated higher into the web, cracking began to occur above the openings. In the moment spans this often took the initial form of two small cracks ascending radially from each hole at about 45° from the vertical, and generally stopping at the web to fillet junction. These were flexural cracks, and their deviation from the vertical was the only evidence of stress concentration noted in the tests. In some instances these two were the first of a small group of similar cracks radiating from the top quarter of the opening perimeters. Those beams failing in flexure and shear-compression also experienced the propagation of single flexural cracks up the middle of the posts in the moment spans from the bottom fibre into the fillet.

By the latter stages of loading the first cracks that had appeared above the first hole outside the moment span usually had grown into the fillet towards the load point, still inclined at about 45°. Even at considerably high loads the upper webs immediately above these holes remained relatively free from visible cracking, although this was the location of the final failure crack.

5.3 Classification of Failure Types

The beams were divided into three categories depending on their mode of failure. The flexural group contains all the beams that failed in the desirable flexural manner, indicating that their shear reinforcement was sufficient for them to attain their ultimate capacity. The shear group consists of those beams that failed at loads considerably below the expected flexural capacities, due to insufficient shear strength. The shear-compression group includes the beams that failed at relatively high loads, but in a manner similar to the shear failures. Failures typical of these three types can be seen in Plates 4.13, 4.14, and 4.15.

The last category was labelled shear-compression because of the combination of high shear and compressive stresses in the upper web near the load points prior to failure. This stress condition apparently was the cause of the failures, as evidenced by the occurrence of cracks inclined less than the 45° of a typical shear crack. While these failures were basically shear in nature, they displayed a behaviour almost as desirable as a flexural failure, since they sustained loads and deflections in some cases greater than those of the flexural group.

The definition of flexural failure as "one occurring in the pure moment region", though somewhat strict, was intended to avoid including a failure not clearly a result of flexural effects. As predicted by strain-compatibility analyses, all flexural failures occurred by the crushing of concrete in the flange and upper web. Thus it was difficult to identify the basic cause of a failure in a shear span as shear or compressive stress on the evidence of appearance alone. This confusion did not arise in previous tests(3)(4)(10) in which all flexural failures were brought about by rupture of the prestressing strand, because this mode of behaviour is indicative of a flexural failure regardless of the amount of shear stress present.

The shear failures were the simplest to distinguish, not only by the low loads involved, but by the form that they took. Because of the low moments sustained, shear stresses dominated over compressive stresses, and the failures took the form of two diagonal cracks, inclined at about 45°. The first of these appeared in the lower web below a hole in the shear span where the concrete was already weakened by flexural tension cracks. Upon the loss of the ability of the lower web to resist shear stress, the portion it had carried was transferred to the upper web. When the shear capacity of the upper web and flange was reached the second diagonal crack appeared, rending the upper web, usually in a violent manner. Both cracks tended to be positioned such that they penetrated the upper and lower webs at their minimum sections, thus minimizing their total length.

The beams were tested in numerical order, but to provide a more logical sequence for comparing their behaviour, the tests will be described in the next three sections by failure type in ascending order of ultimate capacity, expressed in terms of maximum moment at collapse. The ranges of values of maximum moment of the three failure groups are: shear 1368 to 1680 inch-kips, shear-compression 1824 to 2088 inch-kips, and flexural 2016 to 2095 inch-kips. Comparisons of the shear capacities of beams containing different arrangements of shear reinforcement are included even in cases where the shear spans were of different lengths. Because of the dependence of concrete shear strength on normal stress, and thus on applied moment, these comparisons are intended only as qualitative indications of the effects of altering shear reinforcement.

5.4 Beams Failing in the Shear Mode

This group is the largest, consisting of five beams, failing at moments of from 1368 to 1680 inch-kips. It is interesting to note that only one beam with inclined primary shear reinforcement, AD-11, fell in this category. The stirrups in this beam were placed at 60°, rather than at the more efficient 45°, and were not supplemented by upper or lower web shear reinforcement. A further observation is that all beams containing vertical full-depth stirrups were included in this category.

The beam attaining the lowest maximum moment was AD-1. This was expected, because as well as being lightly reinforced with two vertical #3 stirrups per post, this was the only beam with a hole spacing as small as 16 inches. The failure, however, did not occur in the resulting 6 inch posts but in the web portions above and below the first hole from the South end in the manner described in the previous section. The posts in the shear spans, being only slightly cracked, showed that they could have resisted higher loads but it could not be concluded that their strength would be sufficient to allow a flexural failure.

Exceeding AD-1 in strength by about 5%, AD-2 failed at a maximum moment of 1440 inch-kips. AD-2 was detailed exactly as AD-1, except for its 20 inch hole spacing, and the resulting increased length of the moment span from 8 feet to 8 feet 4 inches. Similar too, was the mode of failure, except that it occurred at the second hole from the North end. As noted before, the concrete in AD-2 had higher measured compressive and tensile strengths, which alone may have been sufficient to cause the difference in strength between the beams. AD-2 was flexurally stiffer than AD-1, probably due to the combination of larger hole spacing and the higher modulus of elasticity associated with higher compressive strength. At a load of 18.5 kips (1332 inch-kips, maximum moment) the centerline deflection of AD-1 was 1.56 inches, while that of AD-2, though longer by 4 inches, was only 1.50 inches.

AD-11 failed at a maximum moment of 1488 inch-kips, only 3.3% higher than that of AD-2. Because it had shorter shear spans this represents a maximum shear force 55% higher. Besides having one less hole in each shear span, AD-11 differed from AD-2 in having three stirrups per post inclined at 60° rather than two vertical stirrups. While AD-11 failed in a manner similar to AD-2, the general inclination of the principal cracks was steeper in the case of AD-11. By intersecting the path that a crack would follow in the absence of shear reinforcement, the stirrups adjacent to the hole tended to force the webs to crack in a different location, and thus at a higher load. In this way the stirrup that is barely visible at the bottom of the web below the hole in Plate 4.11 forced the bottom ends of the cracks to the left, away from the support, while the top ends were still free to remain close to the lowest point on the circumference of the hole. This effect also tended to restrict the volume of lower web that was split severely by the cracks, consequently reducing the amount of residual vertical shear deformation across the hole.

Beams AD-10 and AD-5 were the strongest of the group, reaching maximum moments of 1584 and 1680 inch-kips, respectively. AD-5 was designed and tested first, and when it failed below ultimate flexural capacity, its design was repeated in AD-10, but with a closer spacing of #2 stirrups. It was anticipated that this would increase the shear capacity of the upper and lower web regions and thus allow AD-10 to reach higher loads. This did not occur for two reasons. The #2 bar used for the stirrups in AD-10 came from a batch having a yield stress of only 36 ksi, 8 ksi less than that used in AD-5, resulting in (Av fy / s) values for AD-10 only 2% and 9% higher in the upper and lower webs respectively. Also beam AD-10 was not seated properly with the centre surface of the web coplanar with the axes of the jacks. As well as adversely affecting the strength of AD-10, this misalignment modified the mode of failure from the type exhibited by all of the other beams in the shear group, by inducing transverse components of load. There was far less visible evidence of distress in the lower web. No cracks could be seen to be completely severing the lower web, and none of the reinforcement contained therein was revealed by surface spalling which was so prominent in other beams. The upper web was cracked in the usual way, although the crack opened only slightly, and the failure section did not present as striking a discontinuity in the horizontal lines of the beam as it had in other beams.

The flange, however, was badly damaged by the weak-axis bending and torsion resulting from the transverse components of the loads. These effects added to the already high compressive and shearing stresses in the East side of the flange, causing this region to fail in compression between the load and the hole in the shear span. Collapse progressed slowly enough that it could be seen that the crushing of the flange occurred first, precipitating the final failure of the upper web by a shear-type crack. Slippage along this crack (in a counter-clockwise sense in Plate 4.10) caused the crushing and spalling at the bottom of the hole and the series of unmarked cracks in the lower web, extending from the spalled area to the flake protruding from the bottom of the web towards the support.

Beam AD-5 was the only beam containing upper and lower web stirrups that failed in the shear mode typical of the other beams in this group. The lower web was split by a series of cracks inclined at about 45°, and its surface was broken away exposing three of the enclosed stirrups. In Plate 4.5 these stirrups are inclined more steeply than the 45° at which they were placed because of the counter-clockwise slippage that occurred along the cracks. At the penultimate load of 34 kips a crack appeared at a slope of less than 45°, extending from the topmost point of the hole through the fillet and into the flange. The failure of the beam was brought about by the shear failure of the upper web along this crack after application of the last increment of load.

If it could be assumed that the shear capacity of the test beams was dependent only on the shear reinforcement present, and not at all on the loading configuration, then a beam similar to AD-5 but without upper and lower web stirrups, would fail at 20 kips, the failure load of AD-2. The inclusion of this extra reinforcement would then be responsible for an increase of 75% in the capacity of AD-5. While this figure is rather high, it indicates that the effect of such stirrups is of the same order as that of the 60° full-depth stirrups of AD-11. The manner in which these two schemes of reinforcement achieved higher strengths was different, however. In the case of AD-11 the stirrups adjacent to the hole extended into the upper and lower web regions and intersected the line of the most probable shear crack, thus forcing it to detour along a new route at a higher load. The #2 stirrups of AD-5, by being distributed throughout the upper and lower webs, allowed no such possible detour but required the failure cracks to appear in the usual location at a higher load because of the numerous stirrups to be crossed.

Generally, all of the shear failures in this test series occurred at locations predetermined by the geometry of the circular web openings. The upper and lower webs formed by these holes were necessarily very stocky, and, though only a few inches deep, acted as haunched deep beams failing as such in shear rather than flexure. In contrast, the beams cast in previous tests with long rectangular web openings, were much like Vierendeel trusses having slender beam-column members. In regions of high shear force these members would develop considerable secondary flexural stresses which in some cases led to mechanism failures before the flexural capacity of the beam as a whole could be attained.

5.5 Beams Failing in the Shear-Compression Mode

The four beams in this category made use of two different schemes of shear reinforcement. One combined upper and lower web stirrups with three full-depth stirrups per post inclined at 60°. The other three had two, three, or four 45° stirrups in the posts, with no additional shear reinforcement in the upper and lower webs.

The beam reaching the lowest maximum moment of 1824 inch-kips was AD-9, containing three 45° stirrups per post. Although collapse occurred with little warning, it was apparent that the progression of deterioration of this beam was different from that of the shear failure group. Due to the intrusion of the #3 stirrups into the lower web, the shear cracks developed there opened only slightly and had no serious effects on the shear capacity of that region. Similarly, the upper web remained relatively free of cracks until the latter stages of loading, although it was less protected by the stirrups because of the proximity of the hole to the top surface of the flange. Failure occurred in the upper web due to the combination of high compressive and shear stresses, but at a location above the edge of the hole nearer the support, rather than at the minimum section. Much of the damage visible in Plate 4.9 was caused by the sudden release of the large amount of strain energy contained in the beam, rather than by static stresses. The most obvious examples of this type of damage were the cracks in the lower web aligned along the direction of principal tension instead of across it, and the separation of the fillet from the web to the right of the hole. The loss of portions of the flange and the appearance of cracks coincident with some of the reinforcement in the other end of the beam, were also results of this energy release.

Although having shear spans of different length, AD-2, AD-11, and AD-9 illustrate well the strengthening effect of sloping shear reinforcement in beams containing circular web openings. In these beams the stirrups were placed at 90°, 60°, and 45° respectively, producing ultimate loads of 20, 31, and 38 kips. These successive improvements were not the result of the alignment of the sloped reinforcement with the diagonal tension field alone, but also of their presence in the critical areas of the upper and lower webs made possible by their inclination.

Although failing at a maximum moment of 1872 inch-kips, only slightly higher than that of AD-9, AD-12 seemed to suffer less damage, especially that caused by the dynamic release of strain energy. Crushing occurred above the hole in the South shear span, breaking off small pieces of the flange. The lower web was cracked in the same way as was the lower web of AD-9, but not excessively enough to reveal the steel within. The remainder of the beam retained its well developed regular crack pattern after failure, giving no visual indication that it had resisted stresses capable of destroying its load-carrying capacity.

Beam AD-12, containing the 60° #3 stirrups, was similar to AD-11 except for the addition of #2 stirrups in the upper and lower web in the shear spans. This supplementary reinforcement caused an increase in strength of about 26% over that of AD-11. Comparison with AD-5 shows that the effect of changing the slope of the primary shear reinforcement from 90° to 60°, while retaining the secondary shear reinforcement, was to increase the ultimate load by about 11% from 35 to 39 kips. This was not as much as the increase that would be caused by the same transformation in a beam with no secondary shear reinforcement, because the small stirrups in the upper and lower webs were displaced away from the critical sections to make room for the larger full-depth stirrups.

The maximum moment of 2040 inch-kips reached by AD-7, while not the largest, represents the highest value of shear applied to a beam in the shear-compression group. The design of AD-7 followed the testing of AD-3, in which the effectiveness of sloped primary shear reinforcement was first observed. In anticipation of the higher shear force required to develop the ultimate flexural strength of the beams with shorter shear spans, the upper and lower webs were strengthened in two ways. A double stirrup was placed under each load point extending through the critical sections of the upper webs, providing more protection in these areas than would a single stirrup. As well, the diameter of the openings was reduced to 8 inches, making the webs more accessible to the sloped stirrups, and providing a larger area of concrete to resist shear stresses. Together, these two factors caused the failure load of AD-7 to exceed that of AD-9 by about 12%.

Failure of beam AD-7 was similar to that of AD-9, except that the extent of damage caused by the release of strain energy was greater. Stirrups were uncovered by the cracks opening along their length, and portions of the bottom surface were broken off by cracks following the longitudinal steel in the lower web. Longitudinal cracks also appeared on the top surface of the flange approximately above the compression steel in the upper web, severing a large portion of the flange near the South load point, though not detaching it completely from the beam.

Beam AD-3 failed at a maximum moment of 2088 inch-kips, in a manner strikingly similar to AD-7, as seen in Plates 4.3 and 4.7. The shear force involved, however, was much lower because of the longer shear spans of AD-3, and for this reason two #3 stirrups per post were nearly sufficient to induce a flexural failure. A comparison of this beam with AD-2 provides the best illustration of the effect of changing the slope of the full-depth shear reinforcement, as these two beams were similar in all other respects. AD-2 failed at 20 kips and AD-3 failed at 29 kips. This 45% increase in strength, though not as large as others reported, is significant in that the maximum moment involved is larger than those sustained by two beams failing in flexure.

In general, the beams in the shear-compression group behaved in a more desirable manner than did the beams of the shear group. All failure loads were higher in the shear-compression group, thus ultimate deflections tended to be higher also. The one exception to this rule was AD-9 which reached a deflection of only 2.09 inches, slightly less than the 2.38 inch deflection of AD-5 of the shear group. The ultimate deflections of the rest of the shear-compression group ranged from 5.76 to 10.22 inches, with the value of 7.80 inches for AD-7 exceeding the lowest ultimate deflection of a beam of the same length in the flexural group.

5.6 Beams Failing in the Flexural Mode

The three beams falling in this category failed at maximum moments ranging from 2016 to 2095 inch-kips. These were the only beams containing upper and lower web stirrups in conjunction with full-depth #3 stirrups placed at 45°. In all three cases the shear spans remained relatively intact, while the pure moment regions suffered damage from the dynamic release of strain energy as noted before. The mechanism triggering collapse was different, however, as the upper web and flange failed in compression at a location within the moment region.

Beam AD-6 failed at a maximum moment of 2016 inch-kips, lower than the failure moments of AD-3 and AD-7 of the shear-compression group. Location of the failure section was made evident, prior to complete loss of strength, by the slow spalling of the top surface of the flange which occurred near the first hole in the North end of the moment region. Because of the lower moment, beam AD-6 sustained less damage upon the release of strain energy than did the rest of this group and some of the shear-compression group. The longitudinal reinforcement above the hole was buckled out as in a column-type failure. Two of the #3 stirrups and portions of the longitudinal bars in the bottom of the web were revealed by the cracking.

Most closely related to beam AD-6 are beams AD-5 and AD-9. Beam AD-5 had upper and lower web stirrups at about the same spacing as those in AD-6, but the three full-depth stirrups in each post were placed vertically. The use of the inclined stirrups in AD-6 caused this beam to reach a load of 42 kips per jack, or 20% higher than the 35 kip ultimate load of AD-5. Beam AD-9 was detailed as AD-6 but without upper and lower web shear reinforcement. Its ultimate load was 38 kips, so that the addition of the supplementary shear reinforcement increased the strength of AD-6 by about 11%.

Beam AD-8 failed at a maximum moment of 2076 inch-kips, or at an ultimate load of 43.25 kips per jack. This was the beam most heavily reinforced against shear failure and as a result it sustained the highest shear force applied to any of the beams. In addition to the use of smaller holes and doubled stirrups, as in AD-7, this beam contained upper and lower web stirrups at all hole locations in the shear spans. The upper webs above the end holes in the moment span were also protected by stirrups. This was done in an attempt to shift the location of the failure region towards the beam centerline where failure should theoretically occur because of the dead load moment. It was thought that some mechanism action was inducing erratic shear stresses in the upper web near the load points in the moment span which, combined with the high compressive stress, brought about collapse prematurely. These extra stirrups shifted the failure section to the second hole from the end of the moment span, and kept the region between there and the near load point as intact as the shear span regions. The damage was more severe than in AD-6, as the residual deflection was larger.

Beams AD-7 and AD-8 provide another illustration of the effect of adding supplementary upper and lower web stirrups to a beam containing full-depth stirrups placed at 45°. Because of the efficiency of the primary shear reinforcement, the supplementary shear reinforcement increased the strength of AD-8 by only about 2%. Since it failed in flexure, the shear strength of this beam would probably have been somewhat higher.

Because the shear strengths of beams AD-8 and AD-6 are not known, owing to their failure in the flexural mode, a comparison of their strengths based on differences in their shear reinforcement would have no practical value. That AD-8 reached a higher load than AD-6 was not due to a difference in concrete strengths, as these were 5400 and 6100 psi, respectively. The larger cross-sectional area of the upper web and flange of AD-8 may have had some effect, although the depth of the equivalent rectangular stress block of the strain-compatibility analyses is less than the depth of either upper web. While the stirrups in the upper web in the moment span of AD-8 may have strengthened that section by confining the compression zone, it is unlikely that this alone could have increased the strength of the whole beam. Most probably the explanation is a combination of effects, including local concrete weaknesses, fabrication inaccuracies, and prestressing strand inconsistencies.

The final beam of this study to be reported is AD-4, which reached a maximum moment of 2095 inch-kips. This beam was lightly reinforced with upper and lower web stirrups and only two #3 stirrups per post, but this was sufficient to avoid a shear failure because of the longer shear spans and subsequently lower shear forces. Crushing occurred above the first hole in the South end of the moment span and was accompanied by the usual cracking caused by release of strain energy. Cracks also appeared along the top surface of the flange above the longitudinal reinforcement contained therein.

The difference in ultimate load between AD-4 and AD-3, being only about 0.3%, is an insignificant one. Because of the lower concrete strength of AD-4, 5400 psi compared with 5600 psi for AD-3, it would have had a lower ultimate load than AD-3 if fabricated without the supplementary reinforcement. But since the possible failure locations in the shear spans were protected, mainly by the upper web stirrups, the failure occurred in the moment span at a load about equal to the ultimate load of AD-3. Because of the proximity of the failure load of AD-3 to the flexural ultimate load, these stirrups probably acted to confine the compression zone as well as resist the principal tension stresses.

The results of the three tests reported in this section indicate that the concrete section used, although under-reinforced in the sense that the tensile steel was well yielded, tended to fail in flexure by crushing of the flange, rather than by rupture of the prestressing strand. Thus, from the standpoints of strength and ductility, beams AD-3 and AD-7 could be considered to have failed satisfactorily in flexure, although their failure regions developed in the shear spans. Including these two beams as having failed in flexure, the deflections at ultimate load of this group ranged from about 10.2 to 12.4 inches, and 7.1 to 8.3 inches for the longer and shorter beams respectively.

5.7 General Discussion

The present test series consisted of twelve prestressed concrete tee beams containing large circular web openings. While it was found that the openings decreased beam shear strength and flexural stiffness, the behaviour of these beams was different from that of beams containing rectangular or parallelogram shaped openings.

The mode of flexural failure exhibited by the present series was quite different from that of previous tests. Noticeably lacking was the occurrence of tensile failure of the prestressing strands, the criterion used by

Le Blanc(3) Linder(4) and Sauve(10) to distinguish between shear and flexural failure. This made the classification of failure types more difficult in some cases, and led to the adoption of a third category, shear compression failures. Although failure by strand rupture was probably incipient in some of the beams, it is a little odd, considering the similarity of the test specimens used in all the tests conducted at the University of Alberta, that no beam with round holes failed in this manner, and that no beam with angular holes was reported to have failed in flexure by crushing of the flange. There is not enough evidence, however, to conclude that tensile strand failure was made less likely by the use of circular web openings.

The main problem encountered in introducing openings into the web of a tee beam is to maintain sufficient shear strength to allow the member to attain its flexural capacity. This is because the centre portion of the web, where openings are usually placed, carries most of the shear on the section. Thus the main concern of this test series was to study the behaviour of the beams in shear, rather than in flexure, and to compare this to the effects of more elongated holes of quadrilateral shape.

The tests confirm that the geometry of the web openings had a significant influence on the mode in which shear failures took place. Previous test beams containing long quadrilateral openings often experienced localized flexural failure of the upper and lower webs rather than shear stress-diagonal tension failure, because of the slenderness of these sub-members. Also, the sharp opening corners, although filletted, gave rise to stress concentrations at locations where the secondary bending stresses were already high. In contrast, the circular openings produced upper and lower webs which were shorter and stockier, and thus apparently less susceptible to secondary flexural failure. Shear failures typically occurred by diagonal tension cracking, exhibiting little evidence of distress due to secondary flexural effects or stress concentrations.

As well as lessening the likelihood of secondary flexural failure of the upper and lower webs, the geometry of the round holes governed the locations of possible shear failure cracks. Each of these sub-members had one minimum section located above or below the centre of a hole, at which the shear stress was a maximum. As expected, the beams without upper and lower web shear reinforcement sustained 45° shear failure cracks precisely at these sections. The addition of shear reinforcement in these regions, although increasing shear capacity, was able to shift the crack locations only slightly.

The circular openings also tended to preclude the possibility of shear failure in the posts, which occurred in some of the tests on beams with rectangular or parallelogram shaped openings. Each post had one minimum section, as did the upper and lower webs, but because of the curvature of both sides of the posts, an inclined crack would not be able to take advantage of this. In a beam in which the spacing of circular openings is greater than about 1.4 times the opening diameter, two adjacent openings cannot be connected with a 45° line. Thus any potential diagonal tension crack must be inclined at less than 45°, such that the tension across it is not the principal tensile stress.

While the basic behaviour of the beams was determined by the presence of the circular web openings, it was modified by the use of shear reinforcement. The beams failing at the lowest loads had a very minimal amount of shear reinforcement, which was furthermore confined to the posts. The beams failing in flexure contained shear reinforcement in the posts which also extended into the more critical upper and lower web regions, plus smaller, closely spaced inclined stirrups distributed throughout the upper and lower webs in the shear spans. Arrangements of reinforcement between these two extremes produced beams having strengths between the minimum and maximum strengths recorded.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary

In this investigation, twelve prestressed concrete tee beams containing circular web openings were tested. The principal variables included were arrangement of shear reinforcement, and loading configuration, although hole size and spacing were varied slightly in some of the beams. In all cases two equal point loads were positioned symmetrically on the beams at either four or six feet from the support centerlines. Flexural reinforcement was the same in all beams, consisting of eight #3 bars distributed throughout the section, and five 3/8 inch diameter 250K prestressing strands. Shear reinforcement consisted of various combinations of full-depth #3 "U" stirrups placed at 90°, 60°, or 45°, and #2 closed stirrups in the upper and lower web regions placed at 45°. The concrete section used was of a depth of 20 inches with a 2-inch by 20-inch flange. The openings had diameters of 8 or 10 inches, and were spaced regularly at 16 or 20 inches.

The behaviour of the beams is discussed with respect to visual observation and measurements of deflection, reinforcement strain, and concrete strain. Each beam is classified by failure type into the categories of shear, shear-compression, or flexural to facilitate evaluation of the various shear reinforcement schemes.

6.2 Conclusions

The data and observations obtained as a result of the twelve beam tests led to the following conclusions:

a) The behaviour of the twelve beams with circular web openings was similar in some respects to the behaviour exhibited by the beams tested by Le Blanc(3) Linder(4) and Sauve(10) which contained rectangular and parallelogram shaped openings.

i) The presence of web openings in regions of high shear force tended to make the beams more susceptible to shear failure than similar beams without openings would have been.

ii) The openings decreased flexural stiffness, but in cases where shear reinforcement was sufficient to prevent a shear failure, they had no detrimental effect on the ultimate moment capacity of the section.

b) Geometrically, the effect of the circular web openings on the beams was to shorten the posts and the upper and lower web regions, and to make them stockier by the haunching effect of the curve of the openings. These factors contributed to the lack of shear failures in the posts, and upper or lower web flexural failures.

c) Although initial shear cracks developed at hole sections along a 45° line through the hole centres, the failure cracks tended to penetrate the upper and lower webs at their minimum sections. Strain gauges placed on the supplementary shear reinforcement in the upper and lower webs suggested that shear stress was high at these minimum sections, but also that it decreased significantly away from them. Thus, shear reinforcement concentrated at such locations would probably be more efficient than if distributed evenly throughout the length of the upper and lower webs.

d) The use of supplementary #2 upper and lower web stirrups increased the shear capacity of the beams by significant amounts. The magnitude of such strength increases was less in cases where the #2 stirrups could not be placed at the minimum sections because of the presence of full-depth inclined stirrups.

e) The contribution towards beam shear capacity of the full-depth #3 stirrups depended greatly on their slope. Those placed at 45° proved most effective due both to their efficiency in resisting diagonal tension, and to their presence at the minimum upper and lower web sections, made possible by their inclination.

6.3 Recommendations

a) Different methods of reinforcing the upper and lower web should be considered on the basis of bridging the minimum sections of these areas. Further test data should be collected to aid in the development of design procedures for the upper and lower webs above and below circular openings. Considering these areas as compression or tension members seems a reasonable approach, but further study is needed to determine effective shear areas, and the relative amounts of shear force taken by them.

b) Future testing programs should study the shear strength of the posts by inducing the occurrence of post shear failures. This could be achieved by reducing the spacing of the openings or the area of shear reinforcement provided in the posts.

c) A test series using the same amount of prestressing, but proportioned to fail in flexure by rupture of the prestressing strands, should be tested in order to allow further comparison with previous tests in which this was the normal mode of failure.

d) Test beams containing two web openings in each shear span could be tested with shorter shear spans, to study the effects of a post being completely within a shear span in a beam with severe shear reinforcement requirements.

e) To optimize economy and total hole area, combinations of different hole shapes could be used. In low shear force regions rectangular openings could be used, while in high shear areas parallelogram shaped or circular openings would be more efficient. In addition, oval shaped openings should be tested in an attempt to combine the advantages of circular and rectangular openings.

REFERENCES

1 American Concrete Institute, "Building Code Requirements for Reinforced Concrete", (ACI 318-71).

2 Bresler, B. and MacGregor, J.G., "Review of Concrete Beams Failing in Shear", Proceedings ASCE, Vol. 93, No. ST1, Feb. 1967, pp. 343-372.

3 Le Blanc, E.P., "Parallelogram Shaped Openings in Prestressed Concrete Tee Beams", M.Sc. Thesis, Fall 1971, University of Alberta, Edmonton, Alberta.

4 Linder, R.A., "Large Web Openings in Prestressed Concrete T-Beams", M.Sc. Thesis, Spring 1976, University of Alberta, Edmonton, Alberta.

5 Lorentsen, M., "Holes in Reinforced Concrete Girders", Byggmastaren, Vol. 41, No. 7, July 1962, pp. 141-152.

6 MacGregor, J.G., and Hansen, J.M., "Proposed Changes in Shear Provisions for Reinforced Concrete and Prestressed Concrete Beams", ACI Journal, Proceedings, Vol. 66, No. 4, April 1969, pp. 276-288.

7 Nasser, K., Acavalos, A., Daniel, H.R., "Behavior and Design of Large Openings in Reinforced Concrete Beams", Journal of the American Concrete Institute, Vol. 64, No. 1, January 1967, pp. 25-33.

8 Ragan, H.S., and Warwaruk, J., "Tee Members with Large Web Openings", Journal of the Prestressed Concrete Institute, Vol. 12, No. 4, August 1967, pp. 52-65.

9 Ramey, M., and Tattershall, D.W., "Reinforcing Requirements for Concrete Beams with Large Web Openings", Highway Research Record, No. 424, 1973, pp. 5-21.

10 Sauve, J.G., "Prestressed Concrete Tee Beams with Large Web Openings", M.Sc. Thesis, Fall 1970, University of Alberta, Edmonton, Alberta.

11 Somes, N.F., and Corley, W.G., "Circular Openings in Webs of Continuous Beams", ACI Publication SP-42 "Shear in Reinforced Concrete", Vol. 1, pp. 359-398.

BELFAST BOND
50% COTTON

APPENDIX A

MATERIALS, PROCEDURES, AND APPARATUS

A.1 Materials

a) Cement

In order to allow a short curing period, the cement used in all of the beams was Type III, high-early strength Portland Cement.

b) Aggregate

The coarse aggregate used consisted of pea-gravel with a maximum size of 3/8-inch Typical sieve analyses for this material and the sand used are shown in Tables A.1 and A.2. Both aggregates were obtained from the stockpiles in the laboratory, and have been found satisfactory through their use in previous tests.

c) Concrete Mix

The mix design used by previous investigators(3)(4) was repeated in the present series.

The proportions comprising this design were, by weight:

Cement	1.0
Sand	2.2
Gravel	1.6
Water	0.4 to 0.5

While these proportions were maintained for each batch, total batch weights were varied to avoid material wastage. The water content of the mix was varied to offset the effect of variations in the moisture content of the aggregate so that a slump of about 3 inches would result. Workability of the fresh concrete was an important consideration due to the crowded arrangement of reinforcement in some areas of the forms.

The nominal strength of the cured concrete was 5000 psi, although the measured strengths ranged from 5300 psi to 6100 psi. These values were based on the tests of two standard cylinders per batch. A third cylinder was cast from each batch and tested on its side to obtain the tensile splitting strength of the concrete. These values ranged from 300 psi to 500 psi. Cylinder data for each beam are presented in Table A.3

d) Prestressing Strand

Each beam contained five seven-wire, 3/8-inch diameter strands of grade 250K, complying with ASTM-A-416 specifications. The initial portion of the manufacturer's stress-strain curve is shown in Figure A.1.

e) Reinforcement

The non-prestressed longitudinal reinforcement consisted of #3 deformed bars having a measured yield stress of 55 ksi. The full-depth shear reinforcement consisted of #3 deformed bars of the same yield stress bent into a "U" shape by the supplier. The stirrups placed at 60° were produced in the laboratory by re-bending the longer stirrups that were proportioned for placement at 45°.

The smaller upper and lower web stirrups were manufactured in the laboratory from #2 smooth bars. As noted in the discussion, the steel used for these stirrups was not all from the same heat, and had yield strengths of either 44 ksi or 36 ksi.

A.2 Procedures and Apparatus

a) Formwork

The forms used were designed by Linder. They consisted of pairs of ten-foot long sections built up from 1/8-inch plate and small angles, and lined with varnished 1/2-inch plywood. Small truncated plywood cones were attached to the plywood liners with wood-screws and served to hold the styrofoam void-forms in position by engaging sockets cut into the styrofoam blocks. These cones could be relocated easily without wasting any wood, as the screw-holes were patched to prevent the seepage of water into the form-liners. The forms were bolted together and to a steel channel base which formed the bottom surface of the web. The proper shape was maintained by pipe clamps holding the flange tips at the specified width, and by adjustable braces attached to the forms at the flange tips and to the loading floor.

b) Prestressing Procedure

The shear reinforcement cage was first set up with one half of the form in place between the two reinforced concrete abutments used to transmit the prestress force to the load floor. The prestressing strands were then threaded through the abutments, the form bulkheads, the reinforcement cages, and steel centre-hole dynamometers, and anchored at one abutment with CCL anchoring devices. At the other end they were threaded singly through an electrically driven hydraulic centre-hole jack. The power to the jack was switched off when readings of the strain gauges on the dynamometer indicated that the desired level of prestress had been reached. Another anchoring device was then seated on the strand against the abutment to allow the removal of the jack. When all of the strands had been stressed, the rest of the formwork was assembled and adjusted.

c) Casting Procedure

The concrete was mixed in the laboratory in a nine cubic foot vertical drum mixer. Three batches were required for the longer beams, and two for the shorter ones. The concrete was placed carefully using shovels and a pencil vibrator to avoid any serious honey-combing under the holes and under the prestressing strands. Three cylinders were cast from each batch using the standard procedures for compaction, and then left to set beside the beam.

After about 18 hours the forms were removed and the styrofoam void-forms were punched through the openings. The beam, with the cylinders on its flange, was then covered with wet burlap and plastic tarps, to minimize shrinkage cracking. This condition was maintained for five days, at which time the strands were released, and the beam and cylinders were stored in the laboratory uncovered until the time of the test.

d) Release of Prestress

After the five day moist curing period the strands were cut at one end of the beam. To avoid possible damage by sudden transfer of the prestress force, the strands were evenly heated one at a time over a length of about four feet with an oxy-acetylene torch, to cause relaxation before fracture. This method was apparently effective, as none of the beams failed by loss of bond. When all of the strands had been released, they were cut off close to the ends of the beam with the torch.

e) Prestress Losses

The Demec points used for measuring concrete strain during the tests were mounted on the beam at a section near centerline shortly after removal of the forms. Readings of these were taken before and after release, and just prior to testing. Also just before release, a set of readings of the strain gauges on the dynamometers was taken to determine the strains in the strands after any losses that would occur because of the slippage of the anchorage devices. The changes in strain were used to calculate prestress losses caused by elastic shortening of the beam and inelastic effects such as creep and shrinkage of the concrete, and relaxation of the steel. These calculated values are shown in Table A.4.

f) Testing Procedure

Each beam was tested under two point loads applied by hydraulic jacks acting in compression above the beam. The jacks were mounted on a horizontal distributing beam parallel to the test beam, and held above it by two steel frames straddling the test beam. The jacks could be moved to any location on this distributing beam to accommodate the various loading geometries of the beams. Also attached to each of the two frames was a frame of 5-inch channels arranged so as to restrain the flange tips if the beam tended to tip sideways.

Supports for the beam were provided by two steel roller-wheeled carts riding on steel baseplates bolted to reinforced concrete pedestals. One of these carts was free to roll while the other one was restrained by a threaded rod, thus simulating a simply supported condition.

The loads were applied and controlled with an Amsler hydraulic pump located next to the test setup. When each successive increment of load had been applied, it was maintained at a constant level until the beam reached a stable equilibrium and all of the readings had been recorded. At times it was noticed that the jacks were leaning toward the rolling support due to the elongation of the bottom fibre. In such cases the position of the fixed support was adjusted to minimize this condition by means of the threaded rod. At large deflections, however, the jacks tended to lean excessively towards each other because of the shortening of the top fibre. To avoid damage to the jacks it was sometimes necessary to carefully remove the load, shim the jack heads into new positions on the beam, and then re-apply the load before continuing.

TABLE A.1

SIEVE ANALYSIS OF SAND

SIEVE SIZE	WEIGHT RETAINED (grams)	PERCENT RETAINED	CUMULATIVE PERCENT RETAINED	A.S.T.M. STANDARD
#4	17.5	3.0	3.0	0-5
#8	85.2	14.7	17.7	-
#16	54.6	9.5	27.2	20-55
#30	60.0	10.3	37.5	-
#50	208.4	35.8	73.3	70-90
#100	122.9	21.1	94.4	90-98
PAN	17.8	3.1	-	-
SILT	14.4	2.5	-	-
TOTAL	580.8	100.0		

FINENESS MODULUS 2.53

TABLE A.2

SIEVE ANALYSIS OF COARSE AGGREGATE

SIEVE SIZE	PERCENT RETAINED	CUMULATIVE PERCENT RETAINED
3/4	0.0	0.0
3/8	5.9	5.9
#4	87.1	93.0
PAN	7.0	100.0
TOTAL	100.0	

TABLE A.3

SUMMARY OF CONCRETE STRENGTHS

BEAM	MIX NO.	AGE (days)	MEAN CYLINDER STRENGTH (psi)	SPLITTING STRENGTH (psi)
AD-1	1	27	5137	407
	2		5429	371
	3		5394	380
AD-2	1	23	5977	380
	2		5924	473
	3		5760	508
AD-3	1	23	4739	398
	2		5977	345
	3		6145	398
AD-4	1	22	5553	539
	2		5146	495
	3		5544	464
AD-5	1	34	4943	451
	2		5933	451
AD-6	1	30	6119	464
	2		5995	429
AD-7	1	15	5491	407
	2		5624	371
AD-8	1	20	5385	371
	2		5447	380
AD-9	1	29	5438	424
	2		5464	398
AD-10	1	36	5460	442
	2		5915	469
AD-11	1	19	5084	314
	2		5562	292
AD-12	1	21	5800	398
	2		6057	442

TABLE A.4

SUMMARY OF PRESTRESS LOSSES

BEAM	INITIAL PRESTRESS (ksi)	ELASTIC LOSS (ksi)	TIME LOSS (ksi)	TOTAL LOSS (ksi)	EFFECTIVE PRESTRESS (ksi)
AD-1	172.7	21.0	22.9	43.9	128.8
AD-2	172.7	19.6	19.2	38.8	133.9
AD-3	172.6	16.5	17.7	34.2	138.4
AD-4	172.2	16.7	20.4	37.1	135.1
AD-5	177.4	16.1	22.0	38.1	139.3
AD-6	177.9	18.6	19.1	37.7	140.2
AD-7	175.8	18.9	16.5	35.4	140.4
AD-8	177.0	22.0	18.2	40.2	136.8
AD-9	176.5	19.1	23.3	42.4	134.1
AD-10	176.5	20.0	26.3	46.3	130.2
AD-11	175.9	17.1	16.1	33.2	142.7
AD-12	175.9	17.7	16.8	34.5	141.4

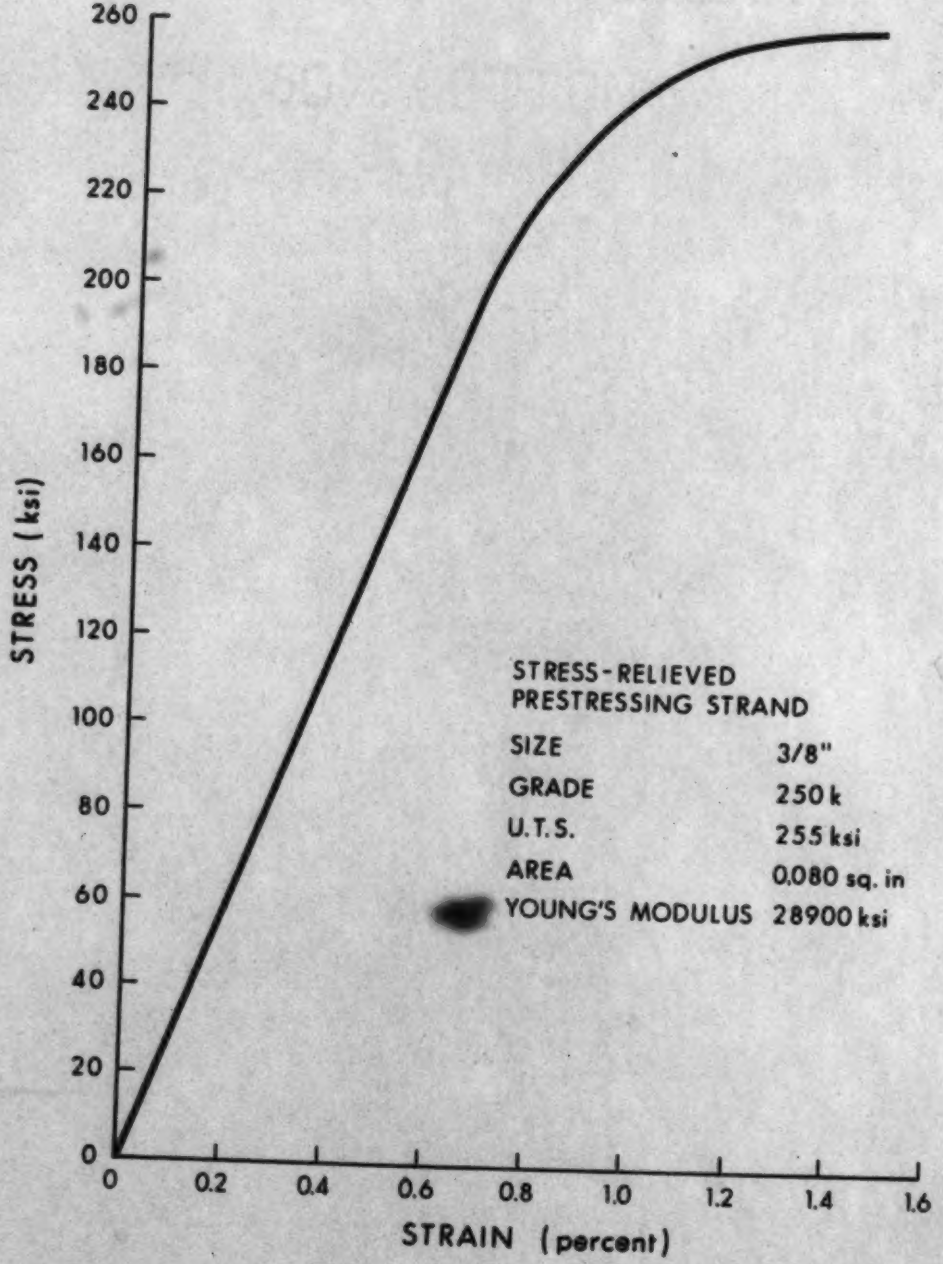


FIGURE A.1

STRAND STRESS-STRAIN CURVE

APPENDIX B

DATA

This appendix contains a drawing of each beam showing the locations of the shear reinforcement and strain gauges, as well as tables of data recorded during the tests. For clarity the readings are referenced to zero applied load, and are given in the basic units of inches for deflection and microinches per inch for strain. Tensile strains and downward deflections are noted as positive.

The electrical strain gauges used had a rated resistance of 120 ohms and a gauge factor of 2.02 for those placed on the prestressing steel, and 2.095 for those placed on non-prestressed reinforcement. The demec points were located at 8-inch gauge lengths at or near beam centerline as depicted in Figure 3.4.

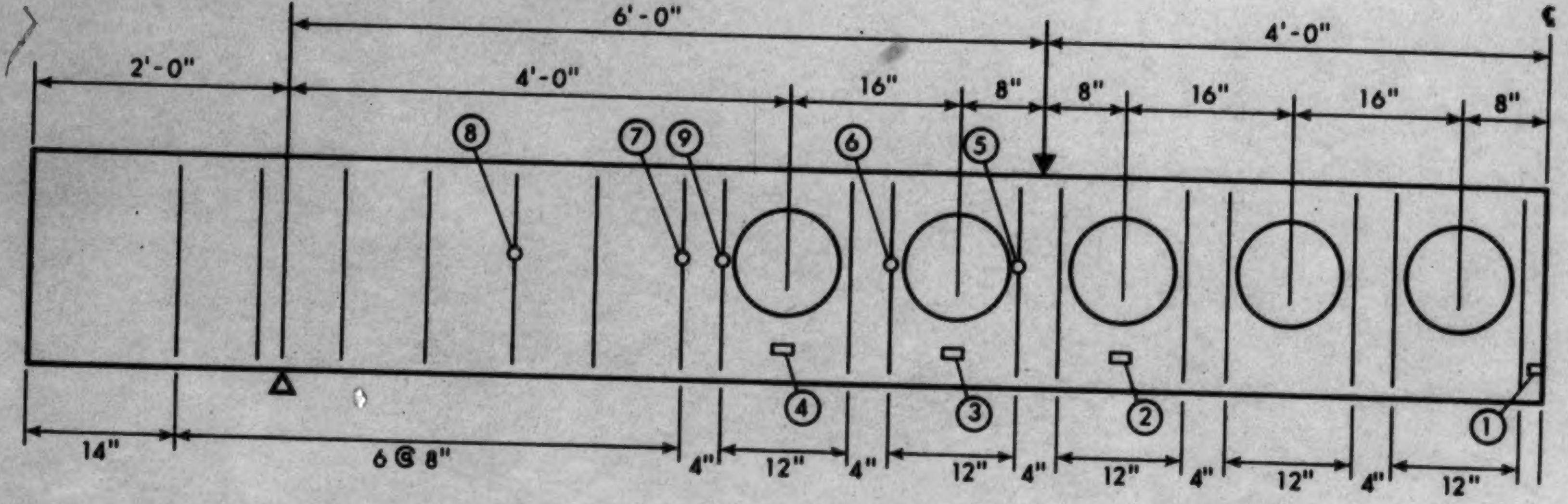


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FIGURE B.1 BEAM AD-1 REINFORCEMENT AND GAUGE DETAILS

TABLE B.1.1.1

STRAIN GAUGE DATA BEAM AD-1

LOAD (kips)	(1)	(2)	(3)	(4)
0.0	0	0	0	0
1.0	40	45	35	25
2.0	80	75	65	50
3.0	110	110	100	70
4.0	150	145	130	90
5.0	185	180	160	110
6.0	230	220	200	135
7.0	280	270	245	160
8.0	325	315	285	185
9.0	385	365	340	215
10.0	465	435	410	245
11.0	625	535	525	285
12.0	860	875	750	330
13.0	1075	1185	925	390
13.5	1220	1250	1015	435
14.0	1355	1365	1120	530
14.5	1490	1470	1200	700
15.0	1620	1590	1290	775
15.5	1770	1720	1380	880
16.0	1890	1835	1460	955
16.5	2040	1955	1560	1030
17.0	2165	2065	1650	1110
17.5	2315	2195	1755	1190
18.0	2450	2320	1855	1275
18.5	2650	2480	2000	1365
19.0				

TABLE B.1.1.2

STRAIN GAUGE DATA BEAM AD-1

LOAD (kips)	(5)	(6)	(7)	(8)	(9)
0.0	0	0	0	0	0
1.0	-5	15	5	0	5
2.0	-10	30	5	0	10
3.0	-15	90	5	0	10
4.0	-15	195	10	0	20
5.0	-30	335	25	0	40
6.0	-45	430	35	0	60
7.0	-60	580	50	-5	145
8.0	-70	680	50	-5	190
9.0	-80	780	65	-5	300
10.0	-80	880	70	-5	345
11.0	-70	970	70	-5	545
12.0	-50	1005	75	-5	640
13.0	-15	1015	90	-5	740
13.5	35	1015	95	-5	775
14.0	205	1020	105	-5	830
14.5	570	1035	110	0	850
15.0	620	1035	110	0	890
15.5	655	1045	115	0	925
16.0	690	1050	120	0	960
16.5	740	1055	125	0	1000
17.0	770	1075	125	0	1040
17.5	795	1110	130	0	1060
18.0	825	1165	135	0	1125
18.5	870	1215	140	0	1180
19.0					1265

TABLE B.1.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-1

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T. A.T.	1744 862	1558 804	1098 666		519 441
0.0	0	0	0		0
1.0	49	49	29		-10
2.0	88	69	49		-20
3.0	147	118	88		-10
4.0	176	147	98		-39
5.0	225	176	108		-39
6.0	265	235	137		-20
7.0	343	265	157		-49
8.0	431	333	186		-49
9.0	519	382	196		-69
10.0	647	470	245		-78
11.0	892	608	284		-69
12.0	1196	813	314		-69
13.0	1470	1029	441		-39
13.5	1637	1117	480		-49
14.0	1813	1274	559		-39
14.5	1960	1392	608		-49
15.0	2107	1490	666		-29
15.5	2264	1627	755		-29
16.0	2411	1744	813		-29
16.5	2577	1872	872		-20
17.0	2744	1980	941		-10
17.5	2920	2146	1009		0
18.0	3067	2264	1068		20
18.5	3273	2430	1137		29
19.0					

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.1.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-1

LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	431	470	402	382
A.T.	402	441	392	372
0.0	0	0	0	0
1.0	-49	-49	-49	-49
2.0	-69	-78	-78	-78
3.0	-108	-118	-118	-118
4.0	-147	-157	-147	-157
5.0	-176	-176	-186	-186
6.0	-206	-216	-225	-225
7.0	-245	-255	-255	-265
8.0	-274	-294	-294	-294
9.0	-314	-333	-333	-343
10.0	-363	-363	-382	-382
11.0	-402	-421	-431	-431
12.0	-461	-470	-500	-500
13.0	-510	-519	-539	-559
13.5	-549	-549	-568	-588
14.0	-578	-578	-598	-627
14.5	-608	-598	-627	-657
15.0	-637	-598	-666	-696
15.5	-666	-666	-696	-725
16.0	-696	-696	-715	-755
16.5	-725	-725	-745	-794
17.0	-755	-735	-764	-823
17.5	-784	-774	-804	-853
18.0	-813	-794	-833	-882
18.5	-853	-833	-862	-911
19.0				

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.1.3

DEFLECTION DATA BEAM AD-1

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
1.0	0.03	0.03	0.03
2.0	0.05	0.06	0.05
3.0	0.07	0.09	0.07
4.0	0.10	0.12	0.10
5.0	0.13	0.15	0.13
6.0	0.15	0.18	0.15
7.0	0.19	0.22	0.19
8.0	0.22	0.26	0.23
9.0	0.26	0.31	0.26
10.0	0.30	0.36	0.30
11.0	0.37	0.44	0.36
12.0	0.47	0.56	0.48
13.0	0.58	0.66	0.58
13.5	0.65	0.77	0.65
14.0	0.71	0.86	0.71
14.5	0.77	0.94	0.78
15.0	0.83	1.01	0.84
15.5	0.89	1.07	0.90
16.0	0.95	1.15	0.97
16.5	1.02	1.23	1.03
17.0	1.08	1.31	1.10
17.5	1.16	1.40	1.17
18.0	1.22	1.46	1.23
18.5	1.30	1.56	1.31
19.0			

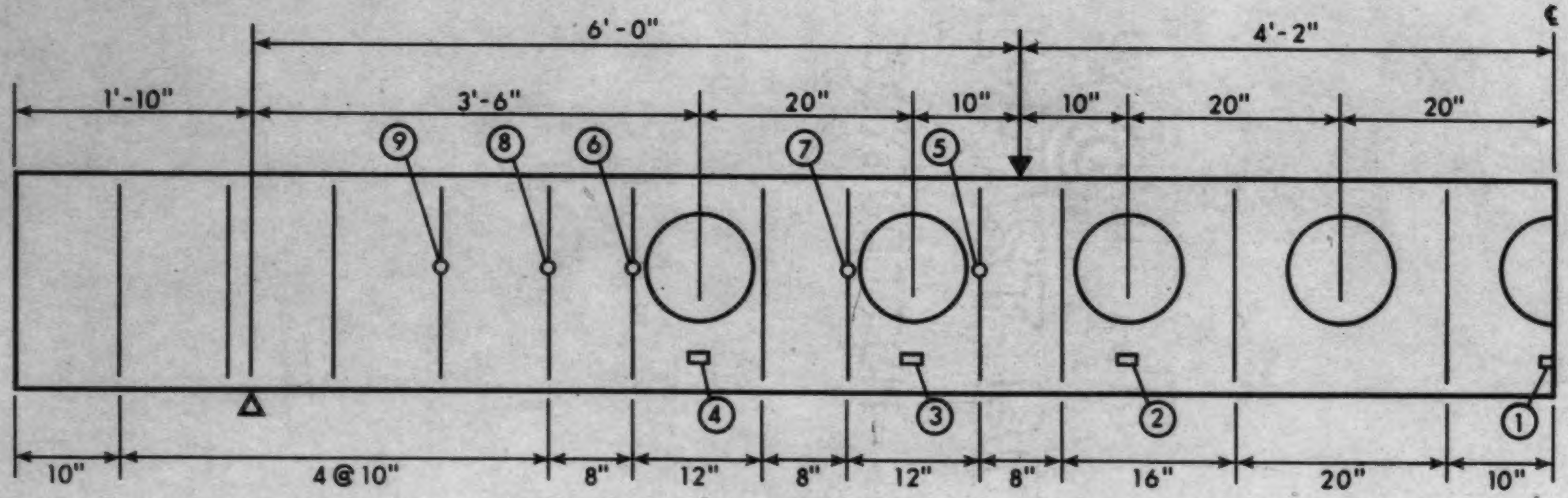
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FIGURE B.2 BEAM AD-2 REINFORCEMENT AND GAUGE DETAILS

TABLE B.2.1.1

STRAIN GAUGE DATA BEAM AD-2

LOAD (kips)	(1)	(2)	(3)	(4)
0.0	0	0	0	0
1.0	25	30	20	15
2.0	55	55	45	30
3.0	90	95	70	50
4.0	125	130	100	65
5.0	160	165	130	85
6.0	200	205	160	100
7.0	240	245	190	120
8.0	290	295	225	140
9.0	335	345	265	165
10.0	400	405	315	190
11.0	475	470	370	220
12.0	765	675	480	255
13.0	1100	1088	740	320
14.0	1325	1300	925	385
15.0	1600	1545	1315	600
15.5	1690	1630	1400	670
16.0	1800	1745	1510	755
16.5	1910	1860	1620	900
17.0	2010	1960	1720	945
17.5	2120	2070	1825	990
18.0	2210	2175	1935	1050
18.5	2320	2285	2050	1110
19.0	2430	2400	2160	1170
19.5	2585	2550	2300	1250
20.0				

TABLE B.2.1.2

STRAIN GAUGE DATA BEAM AD-2

LOAD (kips)	(5)	(6)	(7)	(8)	(9)
0.0	0	0	0	0	0
1.0	-5	5	5	0	0
2.0	-10	10	5	0	0
3.0	-20	20	10	0	0
4.0	-25	30	20	5	-5
5.0	-30	50	30	5	-5
6.0	-45	80	45	5	-5
7.0	-60	120	60	10	-10
8.0	-65	185	100	20	-10
9.0	-65	280	270	25	-10
10.0	-60	420	405	40	-15
11.0	-50	565	595	45	-15
12.0	-10	665	705	50	-20
13.0	75	745	780	50	-20
14.0	170	820	820	50	-20
15.0	375	955	910	50	-20
15.5	425	990	940	50	-20
16.0	465	1025	980	50	-20
16.5	520	965	1025	50	-15
17.0	565	995	1085	50	-15
17.5	605	1030	1135	50	-15
18.0	650	1080	1170	50	-10
18.5	690	1120	1200	50	-10
19.0	725	1160	1240	50	-10
19.5	765	1225	1285	45	-10
20.0		1370	1480		

TABLE B.2.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-2

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1656	1382	941	343	392
A.T.	735	676	539	333	314
0.0	0	0	0	0	0
1.0	20	29	20	0	-29
2.0	59	59	39	-10	-39
3.0	98	88	59	-20	-59
4.0	157	118	88	-10	-59
5.0	206	157	98	-10	-69
6.0	265	196	118	-10	-88
7.0	333	245	147	-10	-88
8.0	392	284	176	-10	-98
9.0	480	353	216	-10	-118
10.0	568	412	225	-20	-147
11.0	715	490	265	-20	-137
12.0	911	588	304	-29	-137
13.0	1274	813	412	-29	-137
14.0	1666	1098	549	-20	-127
15.0	2078	1431	725	0	-118
15.5	2195	1519	804	29	-108
16.0	2381	1656	872	39	-108
16.5	2548	1803	980	69	-108
17.0	2715	1931	1068	98	-88
17.5	2901	2087	1176	137	-88
18.0	3077	2225	1274	147	-88
18.5	3254	2372	1362	186	-78
19.0	3450	2519	1470	216	-69
19.5	2724	2715	1597	255	-69
20.0					

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.2.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-2

LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	402	372	382	412
A.T.	372	333	343	402
0.0	0	0	0	0
1.0	-20	-20	-20	-20
2.0	-39	-29	-39	-39
3.0	-69	-78	-59	-69
4.0	-98	-98	-98	-108
5.0	-127	-137	-127	-127
6.0	-167	-157	-157	-167
7.0	-196	-206	-196	-216
8.0	-235	-235	-216	-245
9.0	-265	-274	-255	-284
10.0	-294	-304	-294	-333
11.0	-333	-343	-333	-372
12.0	-372	-392	-382	-421
13.0	-431	-431	-421	-490
14.0	-480	-480	-480	-549
15.0	-549	-549	-549	-617
15.5	-568	-578	-568	-647
16.0	-598	-608	-598	-686
16.5	-627	-627	-627	-715
17.0	-647	-657	-647	-735
17.5	-686	-706	-696	-794
18.0	-715	-725	-715	-813
18.5	-745	-745	-735	-843
19.0	-774	-784	-774	-872
19.5	-804	-813	-813	-902
20.0				

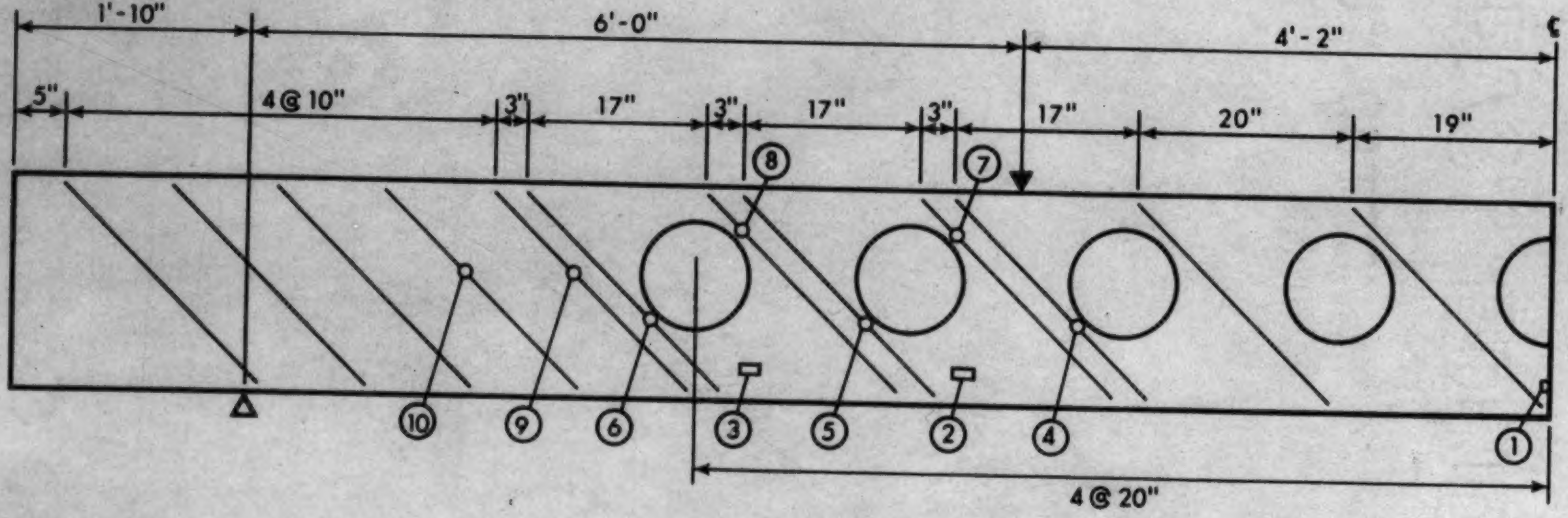
B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.2.3

DEFLECTION DATA BEAM AD-2

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
1.0	0.02	0.02	0.02
2.0	0.04	0.05	0.04
3.0	0.08	0.08	0.07
4.0	0.10	0.11	0.09
5.0	0.13	0.15	0.12
6.0	0.16	0.18	0.15
7.0	0.19	0.22	0.18
8.0	0.23	0.26	0.22
9.0	0.27	0.30	0.25
10.0	0.31	0.35	0.29
11.0	0.36	0.41	0.34
12.0	0.44	0.50	0.41
13.0	0.56	0.65	0.53
14.0	0.67	0.76	0.64
15.0	0.82	0.97	0.79
15.5	0.86	1.03	0.84
16.0	0.92	1.10	0.90
16.5	0.99	1.18	0.97
17.0	1.05	1.25	1.02
17.5	1.12	1.33	1.08
18.0	1.19	1.41	1.15
18.5	1.26	1.50	1.24
19.0	1.32	1.58	1.31
19.5	1.42	1.69	1.41
20.0	1.53	1.81	1.51


1'-10"
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4'-2"
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6
3
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4
1
4 @ 20"

FIGURE B.3 BEAM AD-3 REINFORCEMENT AND GAUGE DETAILS

TABLE B.3.1.1

STRAIN GAUGE DATA BEAM AD-3

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
0.0	0	0	0	0	0
1.0	25	20	15	10	15
2.0	60	45	35	15	40
3.0	90	80	60	20	85
4.0	130	110	80	30	135
5.0	170	140	105	40	215
6.0	215	180	130	45	285
7.0	255	215	150	55	355
8.0	305	255	175	65	435
9.0	350	305	205	75	530
10.0	420	370	235	80	610
11.0	480	435	265	90	670
12.0	640	590	310	95	780
13.0	1000	740	360	95	855
14.0	1350	950	440	140	935
15.0	1590	1110	530	175	990
16.0	1880	1315	680	260	1060
17.0	2090	1510	840	300	1170
18.0	2380	1740	970	340	1310
19.0	2640	1950	1090	410	1415
20.0	3030	2275	1240	435	1520
20.5	3210	2490	1310	460	1580
21.0	3510	2810	1385	475	1650
21.5	3750	3060	1460	490	1720
22.0	4060	3340	1550	520	1790
22.5	4540	3490	1640	540	1860
23.0	5070	3710	1730	560	1930
23.5	6250	3980	1810	565	2000
24.0	7770	4340	1900	565	2060
25.0		5180	2060	540	2080
26.0		6360	2210	540	2035
27.0		6640	2270	490	2010
28.0		7250	2530	485	2070
28.5		8650	2800	460	2060
29.0			2960	460	2040

TABLE B.3.1.2

STRAIN GAUGE DATA BEAM AD-3

LOAD (kips)	(6)	(7)	(8)	(9)	(10)
0.0	0	0	0	0	0
1.0	10	10	15	15	10
2.0	40	25	35	20	10
3.0	75	40	60	30	25
4.0	110	60	85	40	30
5.0	160	85	135	60	40
6.0	205	110	165	65	45
7.0	255	145	215	75	55
8.0	310	180	255	85	65
9.0	375	235	315	95	70
10.0	440	280	360	105	80
11.0	525	355	430	115	90
12.0	610	440	485	120	95
13.0	730	570	560	130	110
14.0	870	700	625	135	115
15.0	1015	815	690	140	120
16.0	1110	915	770	160	135
17.0	1210	1060	925	180	140
18.0	1280	1170	1040	220	155
19.0	1360	1260	1140	270	160
20.0	1450	1360	1235	290	165
20.5	1490	1440	1280	330	175
21.0	1540	1525	1320	345	180
21.5	1580	1630	1370	380	185
22.0	1620	1720	1410	415	190
22.5	1665	1840	1460	455	195
23.0	1710	1940	1510	480	195
23.5	1760	2050	1560	520	205
24.0	1810	2115	1600	550	210
25.0	1890	1940	1685	590	215
26.0	1960	1950	1720	630	230
27.0	1970	2050	1750	670	240
28.0	2040	6200	1820	700	240
28.5	2110		1890	730	260
29.0	2140		1930		

TABLE B.3.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-3

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1490	1215	833	216	294
A.T.	715	627	451	225	235
0.0	0	0	0	0	0
1.0	20	10	0	29	0
2.0	78	59	39	29	-10
3.0	127	98	59	29	-20
4.0	176	127	78	29	-39
5.0	225	157	98	29	-39
6.0	274	206	108	29	-49
7.0	323	245	127	39	-59
8.0	382	294	157	39	-69
9.0	441	333	176	29	-78
10.0	510	392	216	39	-88
11.0	568	451	245	29	-98
12.0	657	519	284	49	-98
13.0	1068	715	363	29	-88
14.0	1637	980	510	39	-88
15.0	1970	1147	608	39	-88
16.0	2381	1411	755	49	-88
17.0	2754	1676	931	49	-88
18.0	3116	1921	1098	69	-78
19.0	3479	2185	1284	78	-78
20.0	3636	2813	1676	98	-69
20.5	4214	3224	1872	108	-49
21.0	5841	3469	2087	118	-29
21.5	6468	3822	2342	127	-10
22.0	7183	5204	2607	147	10
22.5	7860	5655	2960	186	29
23.0	8781	6252	3361	196	39
23.5	9898	7085	3940	255	59
24.0	11290	8095	4635	343	98
25.0					147
29.0					

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.3.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-3

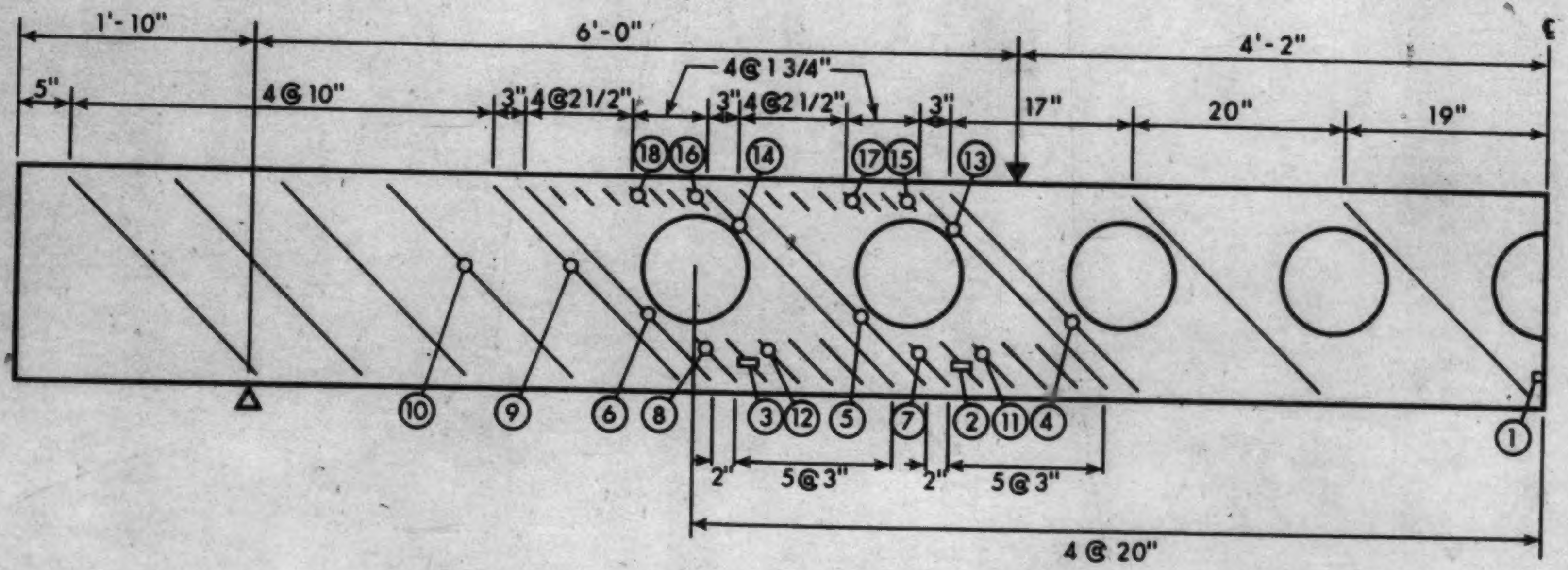
LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	353	382	382	372
A.T.	333	343	343	353
0.0	0	0	0	0
1.0	0	-20	0	-20
2.0	-20	-20	-29	-39
3.0	-49	-69	-59	-78
4.0	-78	-88	-88	-108
5.0	-98	-118	-118	-137
6.0	-127	-137	-147	-167
7.0	-157	-176	-176	-206
8.0	-176	-206	-206	-235
9.0	-216	-245	-245	-284
10.0	-245	-274	-284	-323
11.0	-274	-304	-314	-353
12.0	-314	-323	-343	-392
13.0	-363	-382	-392	-441
14.0	-421	-431	-441	-510
15.0	-451	-441	-480	-549
16.0	-500	-480	-519	-598
17.0	-539	-529	-578	-666
18.0	-588	-578	-617	-715
19.0	-637	-627	-666	-774
20.0	-715	-696	-735	-843
20.5	-755	-725	-755	-892
21.0	-794	-764	-804	-941
21.5	-833	-813	-853	-990
22.0	-872	-853	-892	-1039
22.5	-931	-902	-951	-1098
23.0	-990	-970	-1009	-1166
23.5	-1078	-1039	-1078	-1245
24.0	-1156	-1117	-1156	-1323
25.0				
29.0				

B.T.	BEFORE TRANSFER
A.T.	AFTER TRANSFER

TABLE B.3.3

DEFLECTION DATA BEAM AD-3

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
1.0	0.01	0.02	0.02
2.0	0.03	0.04	0.04
3.0	0.06	0.08	0.07
4.0	0.08	0.11	0.09
5.0	0.11	0.13	0.12
6.0	0.14	0.17	0.15
7.0	0.17	0.20	0.17
8.0	0.20	0.23	0.20
9.0	0.23	0.28	0.23
10.0	0.26	0.31	0.27
11.0	0.30	0.36	0.30
12.0	0.35	0.42	0.36
13.0	0.44	0.53	0.45
14.0	0.56	0.69	0.57
15.0	0.65	0.79	0.65
16.0	0.75	0.92	0.75
17.0	0.85	1.04	0.86
18.0	0.97	1.18	0.97
19.0	1.07	1.30	1.08
20.0	1.22	1.49	1.23
20.5	1.31	1.62	1.33
21.0	1.43	1.76	1.45
21.5	1.54	1.89	1.56
22.0	1.67	2.05	1.68
22.5	1.82	2.25	1.84
23.0	1.99	2.46	2.02
23.5	2.20	2.70	2.23
24.0	2.46	3.07	2.51
25.0	3.47	4.04	3.50
26.0	4.47	5.59	4.67
27.0	5.21	6.66	5.30
28.0	6.08	7.69	6.17
28.5		9.21	
29.0		10.22	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2"
5@3"
4@20"

FIGURE B.4 BEAM AD-4 REINFORCEMENT AND GAUGE DETAILS

TABLE B.4.1.1

STRAIN GAUGE DATA BEAM AD-4

LOAD (kips)	(1)	(2)	(3)	(4)	(5)	(6)
0.0	0		0	0	0	0
2.0	60		40	15	45	40
4.0	125		80	30	125	100
6.0	200		130	45	260	180
8.0	290		180	65	430	280
10.0	400		240	90	585	395
12.0	810		325	110	770	580
14.0	1440		465	140	920	830
15.0	1710		565	190	1040	920
16.0	1960		690	260	1120	1000
17.0	2200		800	310	1310	1085
18.0	2440		910	335	1425	1160
19.0	2700		1040	375	1550	1240
20.0	3050		1200	415	1680	1365
21.0	3700		1330	480	1790	1465
22.0	4400		1470	550	1890	1590
23.0	5240		1640	605	1990	1700
24.0	5340		1815	740	2065	1820
25.0			1990	925	2045	1945
26.0			2150	1080	2020	2045
26.0			2190	1095	2030	2100
27.0			2335	1080	2030	2170
28.0			2630	755	2035	2225
29.0			2880	750	2010	2240
29.0				775	1985	2245
29.1						

TABLE B.4.1.2

STRAIN GAUGE DATA BEAM AD-4

LOAD (kips)	(7)	(8)	(9)	(10)	(11)	(12)
0.0		0	0	0		0
2.0		30	20	15		15
4.0		70	40	30		25
6.0		110	60	40		40
8.0		160	85	60		60
10.0		210	105	75		65
12.0		270	120	90		85
14.0		380	140	110		120
15.0		420	155	120		145
16.0		460	260	125		175
17.0		525	340	140		240
18.0		590	410	145		325
19.0		645	455	155		410
20.0		695	525	170		475
21.0		735	580	175		530
22.0		770	635	185		570
23.0		820	690	195		620
24.0		880	775	210		690
25.0		935	845	215		740
26.0		975	990	240		785
26.0		1005	1055	250		790
27.0		1040	1100	260		815
28.0		1040	1125	265		860
29.0		1045	1150	265		970
29.0			1175	275		945
29.1						

TAB;E B.4.1.3

STRAIN GAUGE DATA BEAM AD-4

LOAD (kips)	(13)	(14)	(15)	(16)	(17)	(18)
0.0	0	0	0	0	0	0
2.0	20	30	10	10	0	0
4.0	70	80	10	10	0	0
6.0	175	190	15	15	-20	-15
8.0	310	315	25	15	-30	-15
10.0	470	435	35	15	-40	-25
12.0	685	595	45	20	-55	-35
14.0	910	770	65	25	-65	-40
15.0	1000	880	75	35	-70	-35
16.0	1070	1010	85	40	-75	-40
17.0	1150	1130	85	45	-80	-40
18.0	1230	1235	90	55	-85	-40
19.0	1310	1335	95	60	-85	-40
20.0	1415	1450	105	70	-85	-40
21.0	1555	1555	110	75	-90	-45
22.0	1710	1640	120	85	-95	-45
23.0	1900	1730	130	95	-95	-45
24.0	2130	1830	140	105	-100	-45
25.0	2300	1900	165	120	-110	-45
26.0	2360	1960	225	140	-115	-45
26.0	2410	1990	390	160	-110	-50
27.0	2420	2025	465	175	-115	-45
28.0	2480	2055	590	180	-125	-50
29.0	2495	2085	845	185	-130	-55
29.0	2420	2080	1045		-125	
29.1						

TABLE B.4.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-4

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1597	1323	892	294	363
A.T.	833	725	510	304	323
0.0	0	0	0	0	0
2.0	59	69	29	10	-10
4.0	167	127	78	10	-20
6.0	265	196	118	20	-39
8.0	372	284	167	20	-69
10.0	490	372	216	20	-88
12.0	686	510	284	10	-98
14.0	1333	853	470	-10	-78
15.0	1588	1019	559	-10	-78
16.0	1842	1215	686	0	-59
17.0	2195	1499	804	10	-59
18.0	2352	1744	921	0	-59
19.0	2617	2009	1068	0	-49
20.0	3205	2499	1323	29	-10
21.0	3587	2911	1597	78	39
22.0	4155	3459	1999	196	98
23.0	4929	3930	2538	323	186
24.0	6742	5939	3567	637	304
25.0	9771	8732	5527	1362	598
26.0					
26.0					
27.0					
28.0					
29.0					
29.0					
29.1					

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.4.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-4

LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	382	441	480	451
A.T.	363	392	431	421
0.0	0	0	0	0
2.0	-39	-39	-29	-39
4.0	-88	-88	-88	-88
6.0	-147	-157	-157	-137
8.0	-206	-216	-216	-216
10.0	-274	-284	-284	-294
12.0	-343	-363	-353	-372
14.0	-451	-451	-441	-490
15.0	-500	-510	-490	-539
16.0	-539	-549	-539	-598
17.0	-588	-598	-588	-657
18.0	-647	-657	-647	-715
19.0	-696	-715	-706	-774
20.0	-784	-794	-784	-862
21.0	-853	-862	-862	-941
22.0	-951	-951	-951	-1049
23.0	-1029	-1039	-1039	-1156
24.0	-1186	-1196	-1205	-1323
25.0	-1450	-1421	-1450	-1578
26.0				
26.0				
27.0				
28.0				
29.0				
29.0				
29.1				

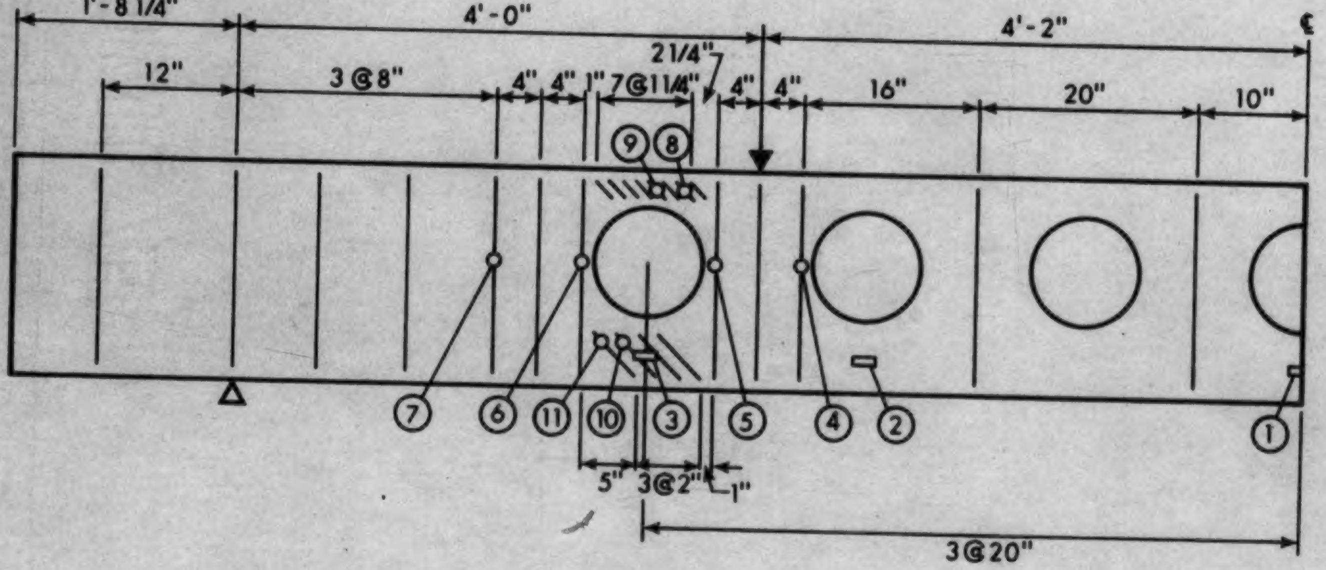
B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.4.3

DEFLECTION DATA BEAM AD-4

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
2.0	0.04	0.04	0.04
4.0	0.09	0.10	0.09
6.0	0.15	0.16	0.14
8.0	0.20	0.23	0.20
10.0	0.26	0.31	0.27
12.0	0.38	0.45	0.38
14.0	0.59	0.71	0.58
15.0	0.68	0.83	0.69
16.0	0.79	0.96	0.79
17.0	0.90	1.08	0.89
18.0	1.00	1.21	1.00
19.0	1.10	1.33	1.10
20.0	1.29	1.57	1.18
21.0	1.45	1.79	1.46
22.0	1.69	2.06	1.67
23.0	1.98	2.38	1.95
24.0	2.40	3.03	2.50
25.0	3.38	4.00	3.26
26.0	5.46	6.84	5.38
26.0	5.73	7.28	5.72
27.0	6.50	8.13	6.41
28.0	8.06	9.96	7.84
29.0	9.20	11.58	9.12
29.0		12.00	
29.1			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2 1/4"
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1"
3 @ 20"

FIGURE B.5 BEAM AD-5 REINFORCEMENT AND GAUGE DETAILS

TABLE B.5.1.1

STRAIN GAUGE DATA BEAM AD-5

BEAM (kips)	(1)	(2)	(3)	(4)	(5)
0.0	0	0	0	0	0
2.0	40	40	30	-5	-15
4.0	80	85	60	-10	-30
6.0	125	125	90	-20	-50
8.0	170	175	120	-15	-105
10.0	215	220	155	-15	-145
12.0	265	275	200	-20	-185
14.0	320	330	250	-25	-210
16.0	390	400	340	-30	-235
17.0	435	440	385	-35	-245
18.0	520	485	450	-40	-250
19.0	625	600	625	-50	-250
20.0	1035	975	725	-50	-250
21.0	1210	1145	815	-60	-245
22.0	1400	1425	925	-75	-215
23.0	1550	1630	1030	-80	-160
24.0	1730	1815	1165	-75	-80
25.0	1880	1965	1300	-80	0
26.0	2050	2125	1440	-80	80
27.0	2200	2275	1600	-75	800
28.0	2380	2460	1790	-70	980
29.0	2550	2635	1990	-80	1155
30.0	2790	2900	2260	-80	1280
31.0	3095	3205	2585	-95	1415
32.0	3650	3700	2930	-115	1560
33.0	4250	4230	3265	-120	1665
34.0	5000	5230	3810	-130	1715
35.0					

TABLE B.5.1.2

STRAIN GAUGE DATA BEAM AD-5

BEAM (kips)	(6)	(7)	(8)	(9)	(10)	(11)
0.0	0	0	0	0	0	0
2.0	15	0	5	10	15	15
4.0	35	5	15	15	35	30
6.0	65	5	25	25	60	50
8.0	160	5	30	15	90	80
10.0	260	15	30	20	130	130
12.0	245	35	35	25	140	190
14.0	310	35	45	30	160	235
16.0	370	30	55	45	185	325
17.0	425	30	60	50	195	375
18.0	440	25	70	60	210	410
19.0	465	25	80	70	245	455
20.0	500	25	110	75	280	500
21.0	580	20	160	85	345	500
22.0	600	20	215	100	400	530
23.0	660	15	300	180	905	735
24.0	840	40	390	290	995	810
25.0	900	45	480	395	1155	955
26.0	965	50	570	500	1270	1045
27.0	1060	50	675	580	1450	1195
28.0	1150	60	740	630	1550	1260
29.0	1270	80	835	715	1630	1320
30.0	1360	100	920	780	1695	1375
31.0	1450	130	995	860	1765	1435
32.0	1570	160	1100	950	1830	1490
33.0	1635	190	1235	1070	1890	1555
34.0	1725	240	1650	1420	1965	1615
35.0						2000

TABLE B.5.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-5

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1676	1352	990	441	519
A.T.	892	774	627	431	470
0.0	0	0	0	0	0
2.0	39	39	20	0	0
4.0	108	88	39	0	-10
6.0	167	127	69	0	-20
8.0	235	167	88	10	-29
10.0	294	206	127	10	-39
12.0	382	265	137	10	-59
14.0	480	323	167	0	-69
16.0	598	402	196	0	-78
17.0	686	451	225	0	-98
18.0	774	519	255	0	-98
19.0	960	588	294	0	-108
20.0	1431	608	343	0	-108
21.0	1803	637	412	0	-118
22.0	2146	686	441	0	-118
23.0	2489	784	539	10	-88
24.0	2822	902	637	29	-88
25.0	3116	1000	755	69	-88
26.0	3420	1078	853	137	-69
27.0	3704	1186	941	186	-69
28.0	3998	1284	1029	255	-59
29.0	4332	1401	1137	314	-39
30.0	5233	1666	1333	363	-39
31.0				470	10
32.0					
33.0					
34.0					
35.0					

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.5.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-5

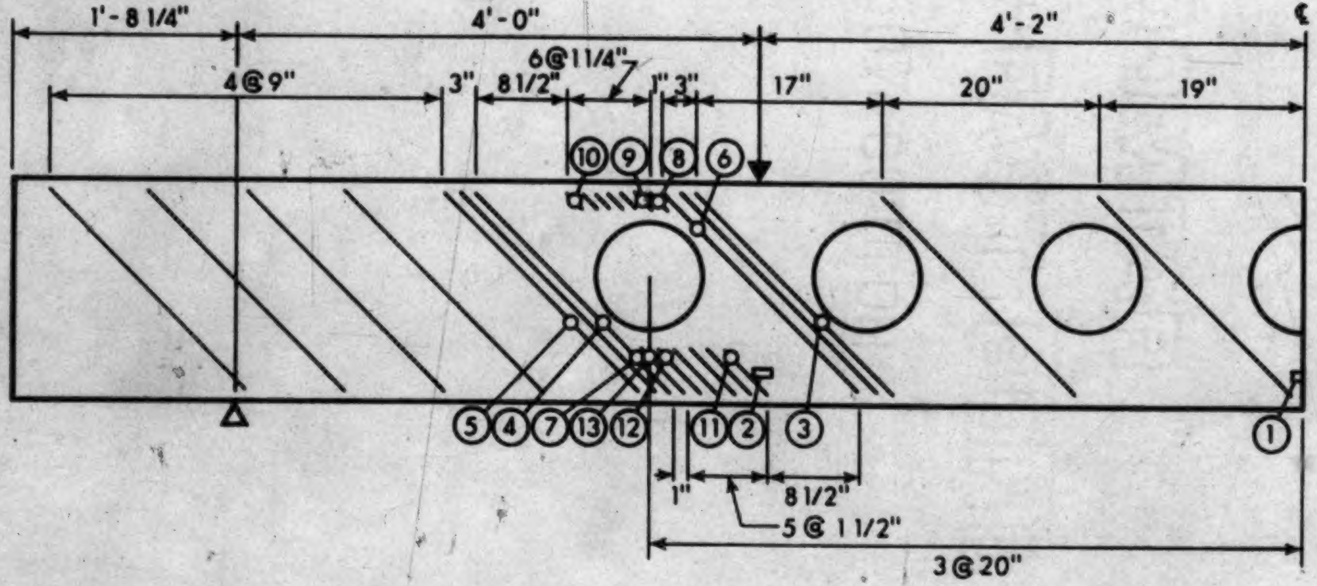
LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	431	392	431	363
A.T.	441	372	412	382
0.0	0	0	0	0
2.0	-39	-29	-29	-29
4.0	-69	-59	-59	-69
6.0	-98	-88	-98	-98
8.0	-147	-127	-137	-147
10.0	-186	-176	-176	-186
12.0	-225	-206	-225	-225
14.0	-274	-255	-255	-274
16.0	-304	-294	-304	-323
17.0	-343	-323	-323	-353
18.0	-470	-353	-353	-372
19.0	-392	-372	-382	-402
20.0	-431	-402	-412	-441
21.0	-461	-431	-441	-470
22.0	-500	-470	-480	-519
23.0	-539	-500	-500	-549
24.0	-578	-539	-549	-588
25.0	-617	-568	-588	-627
26.0	-647	-598	-627	-657
27.0	-706	-627	-666	-696
28.0	-735	-676	-696	-735
29.0	-774	-715	-735	-784
30.0	-843	-784	-813	-853
31.0				
32.0				
33.0				
34.0				
35.0				

B.T.	BEFORE TRANSFER
A.T.	AFTER TRANSFER

TABLE B.5.3

DEFLECTION DATA BEAM AD-5

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
2.0	0.01	0.02	0.02
4.0	0.03	0.05	0.04
6.0	0.05	0.07	0.06
8.0	0.07	0.10	0.08
10.0	0.09	0.13	0.10
12.0	0.12	0.16	0.13
14.0	0.14	0.19	0.16
16.0	0.18	0.24	0.19
17.0	0.20	0.26	0.21
18.0	0.22	0.29	0.23
19.0	0.26	0.33	0.27
20.0	0.31	0.41	0.32
21.0	0.36	0.47	0.37
22.0	0.41	0.55	0.43
23.0	0.46	0.62	0.48
24.0	0.52	0.69	0.54
25.0	0.57	0.76	0.59
26.0	0.62	0.83	0.63
27.0	0.67	0.89	0.69
28.0	0.72	0.97	0.74
29.0	0.79	1.05	0.81
30.0	0.89	1.19	0.91
31.0	1.00	1.34	1.02
32.0	1.13	1.52	1.15
33.0	1.27	1.71	1.29
34.0	1.47	1.96	1.49
35.0		2.38	


1'-8 1/4"
4'-0"
4'-2"
℄
4@9"
3"
8 1/2"
6@1 1/4"
1"
3"
17"
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19"
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9
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13
12
11
2
3
1
1"
8 1/2"
5@1 1/2"
3@20"

FIGURE B.6 BEAM AD-6 REINFORCEMENT AND GAUGE DETAILS

TABLE B.6.1.1

STRAIN GAUGE DATA BEAM AD-6

LOAD (kips)	(1)	(2)	(3)
0.0	0	0	0
2.0	35	40	5
4.0	80	70	10
6.0	120	115	10
8.0	170	160	20
10.0	220	210	25
12.0	270	260	35
14.0	330	330	45
16.0	400	420	60
18.0	505	590	60
20.0	1050	845	45
22.0	1360	1110	80
24.0	1675	1430	135
26.0	2015	1710	165
28.0	2360	1975	195
30.0	2770	2250	220
32.0	3860	3020	300
34.0	5570	3600	405
35.0	6800	3990	470
36.0	9040	4430	545
37.0	13400	5080	590
38.0	15000	5700	570
39.0		6150	645
39.0			920
40.0			910
41.0			920
42.0			

TABLE B.6.1.2

STRAIN GAUGE DATA BEAM AD-6

LOAD (kips)	(4)	(5)	(6)	(7)	(8)
0.0	0	0	0	0	0
2.0	25	20	20	25	5
4.0	55	40	60	60	10
6.0	100	60	115	90	15
8.0	145	90	185	130	20
10.0	190	130	255	175	30
12.0	240	165	330	230	35
14.0	305	195	410	315	45
16.0	365	230	540	480	60
18.0	550	355	670	745	80
20.0	670	460	810	950	100
22.0	795	580	950	1130	130
24.0	930	690	1060	1310	235
26.0	1050	810	1150	1490	400
28.0	1175	910	1270	1670	535
30.0	1310	1040	1370	1860	610
32.0	1500	1200	1560	2050	725
34.0	1800	1340	1730	2260	820
35.0	1890	1390	1830	2315	875
36.0	1960	1450	2000	2395	940
37.0	2015	1520	3150	2370	1050
38.0	2020	1570	4770	2370	1160
39.0	2020	1625	6250	2365	1290
39.0	2090	1730	9040	2390	1675
40.0	2110	1780	9850	2410	1780
41.0	2120	1840		2400	1990
42.0					

TABLE B.6.1.3

STRAIN GAUGE DATA BEAM AD-6

LOAD (kips)	(9)	(10)	(11)	(12)	(13)
0.0	0	0	0	0	0
2.0	0	0	0	20	20
4.0	5	-5	10	40	40
6.0	5	-10	10	55	60
8.0	10	-10	20	80	80
10.0	10	-20	25	100	105
12.0	15	-20	35	130	130
14.0	20	-25	55	160	180
16.0	30	-30	80	195	215
18.0	45	-35	130	265	260
20.0	60	-40	180	370	350
22.0	80	-40	280	540	450
24.0	120	-45	340	730	565
26.0	190	-50	400	860	665
28.0	270	-35	440	945	735
30.0	330	-30	480	1040	790
32.0	410	-30	500	1145	850
34.0	490	-30	530	1255	900
35.0	570	-20	540	1285	935
36.0	630	-20	540	1325	940
37.0	730	-20	550	1350	950
38.0	840	-25	545	1360	940
39.0	945	-25	560	1375	940
39.0	1230	-10	530	1360	905
40.0	1320	-10	530	1380	910
41.0	1520	-10	530	1420	915
42.0					

TABLE B.6.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-6

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1617	1343	921	333	412
A.T.	715	676	510	323	343
0.0	0	0	0	0	0
2.0	49	49	20	10	0
4.0	108	69	39	10	-20
6.0	167	127	69	10	-29
8.0	235	167	98	10	-29
10.0	304	216	108	10	-49
12.0	382	265	137	10	-69
14.0	451	225	167	10	-78
16.0	549	294	206	10	-98
18.0	666	372	255	10	-108
20.0	1176	617	333	10	-108
22.0	1793	892	441	10	-98
24.0	2528	1225	617	39	-88
26.0	3077	1558	794	49	-78
28.0	3665	1852	1000	78	-69
30.0	4361	2244	1284	108	-59
32.0	5713	3009	1872	225	0
34.0	7438	4047	2724	490	78
35.0	9026	4910	3459	657	137
36.0					
37.0					
38.0					
39.0					
39.0					
40.0					
41.0					
42.0					

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.6.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-6

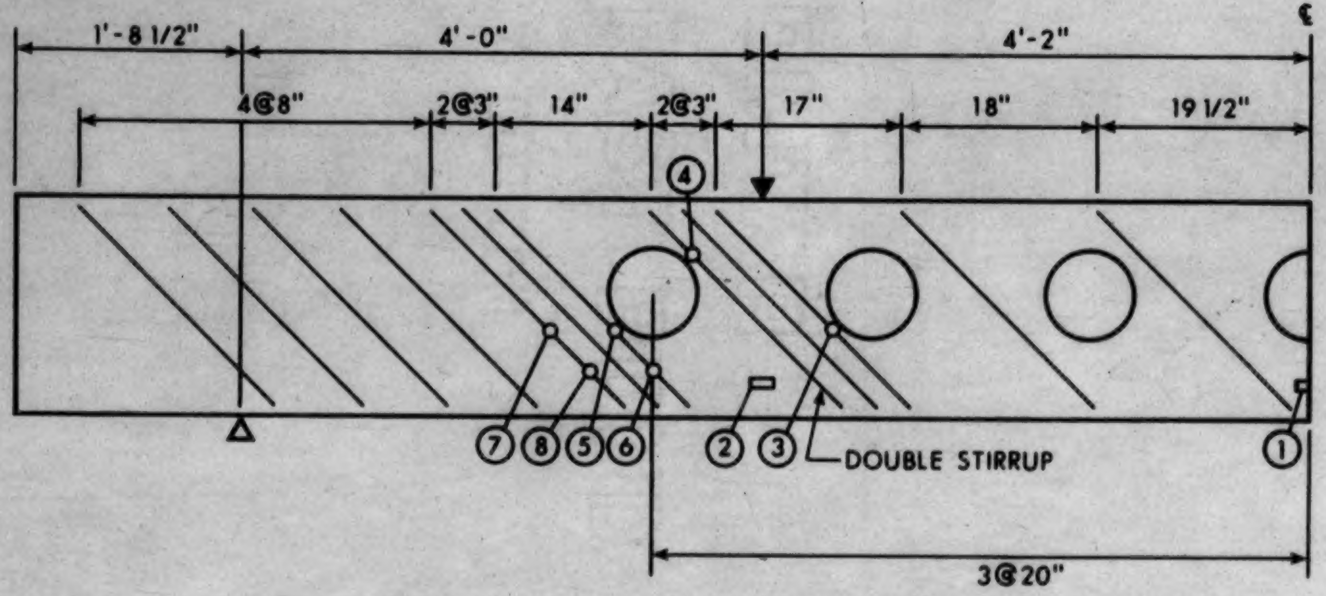
LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	490	500	480	431
A.T.	461	441	441	431
0.0	0	0	0	0
2.0	-10	-29	-29	-20
4.0	-39	-39	-59	-49
6.0	-69	-88	-98	-88
8.0	-98	-108	-127	-127
10.0	-147	-157	-176	-167
12.0	-186	-186	-206	-206
14.0	-216	-235	-255	-255
16.0	-265	-274	-304	-304
18.0	-323	-323	-353	-353
20.0	-392	-402	-421	-431
22.0	-451	-451	-480	-500
24.0	-519	-529	-539	-568
26.0	-578	-578	-598	-637
28.0	-647	-627	-666	-706
30.0	-706	-696	-735	-794
32.0	-853	-843	-872	-941
34.0	-990	-970	-1019	-1098
35.0	-1078	-1058	-1117	-1205
36.0				
37.0				
38.0				
39.0				
39.0				
40.0				
41.0				
42.0				

B.T.	BEFORE TRANSFER
A.T.	AFTER TRANSFER

TABLE B.6.3

DEFLECTION DATA BEAM AD-6

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
2.0	0.02	0.02	0.02
4.0	0.04	0.05	0.04
6.0	0.06	0.08	0.06
8.0	0.08	0.10	0.08
10.0	0.10	0.13	0.10
12.0	0.12	0.16	0.13
14.0	0.14	0.19	0.15
16.0	0.17	0.23	0.18
18.0	0.21	0.27	0.21
20.0	0.29	0.38	0.28
22.0	0.37	0.50	0.37
24.0	0.45	0.62	0.45
26.0	0.54	0.74	0.54
28.0	0.62	0.85	0.62
30.0	0.72	0.99	0.73
32.0	0.90	1.24	0.90
34.0	1.15	1.58	1.16
35.0	1.30	1.81	1.32
36.0	1.51	2.08	1.51
37.0	1.92	2.72	1.96
38.0	2.56	3.57	2.58
39.0	2.87	4.09	2.88
39.0	3.41	4.84	3.39
40.0	3.61	5.11	3.58
41.0	4.18	5.92	4.08
42.0		7.12	


1'-8 1/2"
4'-0"
4'-2"
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4@8"
2@3"
14"
2@3"
17"
18"
19 1/2"
④
⑦
⑧
⑤
⑥
②
③
DOUBLE STIRRUP
①
3@20"

FIGURE B.7 BEAM AD-7 REINFORCEMENT AND GAUGE DETAILS

TABLE B.7.1.1

STRAIN GAUGE DATA BEAM AD-7

LOAD (kips)	(1)	(2)	(3)	(4)
0.0	0	0	0	0
2.0	40	35	0	15
4.0	90	80	5	30
6.0	140	130	5	45
8.0	190	180	10	65
10.0	245	230	15	105
12.0	310	290	20	175
14.0	370	350	30	235
16.0	450	430	35	315
18.0	545	545	40	400
20.0	830	740	15	520
22.0	1205	970	-10	650
24.0	1580	1285	30	800
26.0	1885	1550	75	940
28.0	2245	1825	120	1070
30.0	2620	2090	175	1195
32.0	3745	2415	270	1350
33.0	4430	2770	340	1430
34.0	5075	3010	445	1545
35.0	5990	3250	545	1630
36.0	8000	3550	640	1740
37.0	12700	4005	730	1860
38.0	17500	4410	895	1990
39.0	20000	4890	1140	2115
39.0		5055	1250	2130
40.0		5450	1385	2265
41.0		6000	1465	2500
42.0		6600	1475	2900
42.5				3300

TABLE B.7.1.2

STRAIN GAUGE DATA BEAM AD-7

LOAD (kips)	(5)	(6)	(7)	(8)
0.0	0	0	0	0
2.0	20	30	10	20
4.0	55	60	25	45
6.0	110	95	40	70
8.0	175	130	60	95
10.0	270	170	80	125
12.0	375	210	110	155
14.0	485	255	140	185
16.0	635	300	180	215
18.0	745	365	220	250
20.0	810	460	275	315
22.0	900	680	330	405
24.0	985	950	415	510
26.0	1100	1165	585	595
28.0	1205	1365	690	680
30.0	1340	1590	870	780
32.0	1490	1800	1005	925
33.0	1545	1910	1060	990
34.0	1620	2020	1130	1050
35.0	1700	2120	1190	1105
36.0	1790	2220	1275	1150
37.0	1870	2320	1355	1190
38.0	1930	2400	1445	1220
39.0	1910	2415	1525	1230
39.0	1905	2390	1520	1240
40.0	1915	2420	1570	1260
41.0	1880	2425	1585	1280
42.0	1840	2440	1600	1320
42.5				

TABLE B.7.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-7

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1470	1264	853	216	323
A.T.	637	588	412	157	255
0.0	0	0	0	0	0
2.0	49	39	20	10	-10
4.0	108	88	39	10	-20
6.0	186	127	59	10	-49
8.0	245	196	108	20	-49
10.0	314	245	137	20	-59
12.0	382	314	176	20	-78
14.0	451	363	216	29	-98
16.0	549	461	255	29	-108
18.0	647	568	294	29	-118
20.0	902	862	353	29	-127
22.0	1333	1313	490	20	-118
24.0	1852	1813	666	49	-108
26.0	2313	2254	813	69	-98
28.0	2783	2754	1000	88	-78
30.0	3244	3273	1245	118	-69
32.0	4175	4351	1784	284	-10
33.0	4773	4939	2078	412	20
34.0	5772	5762	2411	568	69
35.0	6791	6546	2715	696	118
36.0	8506	7958	3508	921	196
37.0	11231	10319	5263	1284	294
38.0					
39.0					
39.0					
40.0					
41.0					
42.0					
42.5					

B.T.	BEFORE TRANSFER
A.T.	AFTER TRANSFER

TABLE B.7.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-7

LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	245	284	274	196
A.T.	265	284	274	216
0.0	0	0	0	0
2.0	-39	-29	-29	-39
4.0	-69	-69	-69	-78
6.0	-108	-108	-108	-108
8.0	-147	-147	-147	-157
10.0	-176	-186	-176	-206
12.0	-225	-235	-225	-245
14.0	-265	-372	-265	-304
16.0	-314	-323	-314	-353
18.0	-353	-363	-363	-402
20.0	-412	-412	-421	-470
22.0	-490	-480	-490	-549
24.0	-568	-559	-559	-637
26.0	-637	-617	-627	-715
28.0	-706	-686	-706	-804
30.0	-764	-764	-784	-882
32.0	-911	-892	-921	-1029
33.0	-980	-960	-990	-1098
34.0	-1049	-1039	-1068	-1186
35.0	-1127	-1117	-1147	-1284
36.0	-1235	-1235	-1274	-1411
37.0	-1421	-1411	-1460	-1607
38.0				
39.0				
39.0				
40.0				
41.0				
42.0				
42.5				

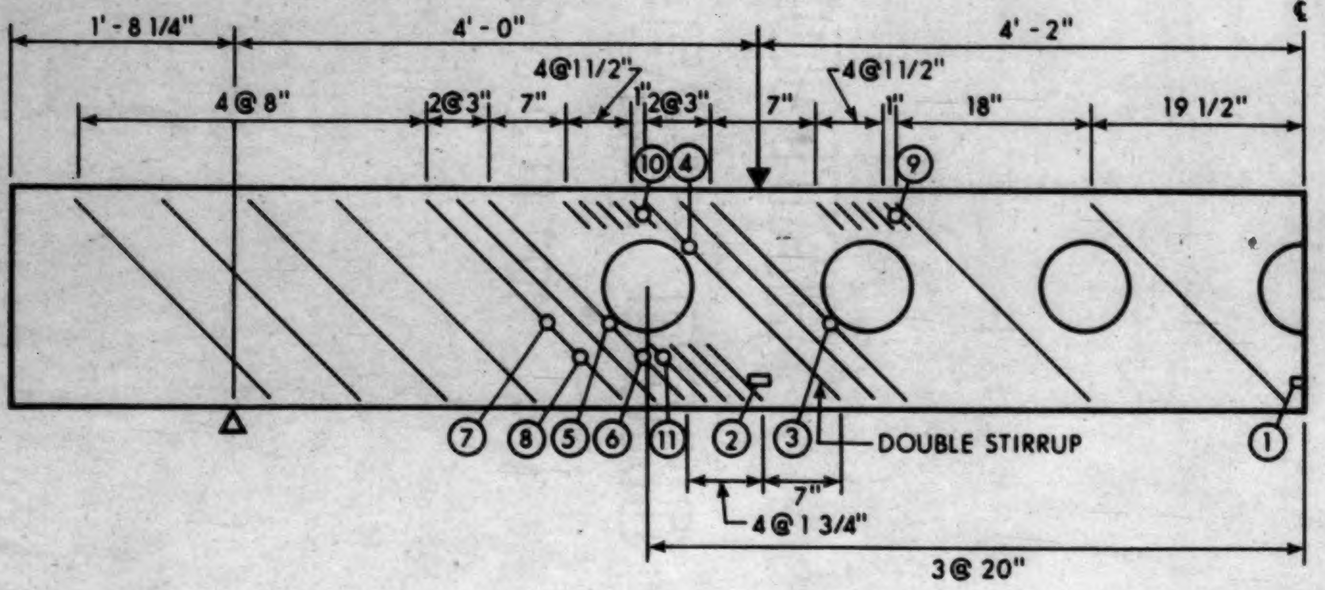
B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.7.3

DEFLECTION DATA BEAM AD-7

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
2.0	0.01	0.02	0.02
4.0	0.03	0.04	0.03
6.0	0.05	0.07	0.05
8.0	0.08	0.10	0.08
10.0	0.11	0.14	0.10
12.0	0.13	0.17	0.13
14.0	0.15	0.20	0.15
16.0	0.19	0.24	0.18
18.0	0.22	0.29	0.21
20.0	0.28	0.37	0.26
22.0	0.37	0.48	0.35
24.0	0.45	0.60	0.43
26.0	0.53	0.72	0.51
28.0	0.61	0.82	0.60
30.0	0.71	0.98	0.69
32.0	0.87	1.19	0.84
33.0	0.97	1.35	0.95
34.0	1.09	1.51	1.06
35.0	1.22	1.70	1.20
36.0	1.42	1.94	1.38
37.0	1.79	2.43	1.71
38.0	2.67	3.70	2.52
39.0	3.22	4.53	3.08
39.0	3.53	4.97	3.41
40.0	4.07	5.78	3.98
41.0	4.49	6.39	4.46
42.0	4.96	7.07	4.92
42.5		7.80	


1'-8 1/4"
4'-0"
4'-2"
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4@8"
2@3"
7"
4@1 1/2"
1"
2@3"
7"
4@1 1/2"
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18"
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2
3
DOUBLE STIRRUP
1
7"
4@1 3/4"
3@20"

FIGURE B.8 BEAM AD-8 REINFORCEMENT AND GAUGE DETAILS

TABLE B.8.1.1

STRAIN GAUGE DATA BEAM AD-8

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
0.0	0	0	0	0	0
2.0	35	40	0	15	20
4.0	75	80	0	65	50
6.0	125	125	-5	125	85
8.0	170	175	-5	185	125
10.0	225	225	-5	260	180
12.0	280	285	0	340	240
14.0	345	350	0	430	315
16.0	420	430	0	550	515
18.0	525	540	-15	655	645
20.0	975	750	-105	785	710
22.0	1350	1000	-115	915	810
24.0	1675	1240	-95	1025	940
26.0	1985	1510	-45	1125	1065
28.0	2285	1720	-20	1235	1215
30.0	2615	1940	5	1345	1355
32.0	3800	2200	55	1460	1495
34.0	4950	2885	115	1600	1620
36.0	6410	3390	225	1790	1740
38.0	10060	4350	345	2015	1820
40.0	5590	5170	490	2175	1820
40.0	5170	5270	410	2230	1940
42.0		6420	110	2235	1915
43.2					

TABLE B.8.1.2

STRAIN GAUGE DATA BEAM AD-8

LOAD (kips)	(6)	(7)	(8)	(9)	(10)	(11)
0.0	0	0	0	0	0	0
2.0	25	15	15	-10	0	15
4.0	55	25	35	-20	0	35
6.0	85	45	60	-35	-5	55
8.0	120	70	80	-50	-5	80
10.0	150	100	105	-65	-5	105
12.0	190	130	130	-70	0	140
14.0	235	175	165	-90	10	175
16.0	300	240	210	-100	20	210
18.0	380	290	260	-115	30	275
20.0	670	380	345	-130	45	360
22.0	860	595	405	-145	65	465
24.0	1085	750	475	-160	90	630
26.0	1300	880	570	-175	115	745
28.0	1495	1005	765	-180	145	850
30.0	1710	1090	890	-170	180	945
32.0	1930	1210	1000	-80	215	1055
34.0	2140	1360	1085	-5	290	1150
36.0	2330	1470	1135	75	375	1210
38.0	2450	1615	1180	235	480	1250
40.0	2390	1720	1210	250	590	1240
40.0	2355	1910	1100	200	855	1215
42.0	2325	1980	1165	220	945	1230
43.2						

TABLE B.8.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-8

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1695	1421	1078	314	382
A.T.	725	637	549	225	274
0.0	0	0	0	0	0
2.0	59	39	29	10	-10
4.0	118	98	59	0	-29
6.0	186	147	88	10	-49
8.0	255	196	118	10	-78
10.0	333	255	167	10	-88
12.0	412	323	216	10	-108
14.0	500	392	255	20	-118
16.0	637	480	314	69	-137
18.0	951	676	412	78	-157
20.0	1529	1127	578	59	-157
22.0	2127	1627	902	98	-147
24.0	2685	2107	1235	118	-137
26.0	3067	2509	1558	147	-127
28.0	3508	2891	1872	206	-118
30.0	3969	3342	2234	294	-108
32.0	5410	4439	3058	490	-29
34.0	7223	5811	4038	676	39
36.0	9575	7644	5400	892	137
38.0	16768	14465	11143	1784	598
40.0					
40.0					
42.0					
43.2					

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.8.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-8

LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	441	343	333	323
A.T.	451	323	323	333
0.0	0	0	0	0
2.0	0	69	-29	-29
4.0	-29	-69	-59	-59
6.0	-69	-108	-108	-88
8.0	-108	-157	-157	-137
10.0	-157	-196	-196	-176
12.0	-196	-245	-245	-216
14.0	-245	-294	-284	-265
16.0	-284	-343	-343	-314
18.0	-323	-392	-392	-363
20.0	-412	-470	-451	-441
22.0	-470	-529	-519	-519
24.0	-549	-598	-588	-598
26.0	-637	-676	-647	-676
28.0	-696	-755	-725	-755
30.0	-774	-833	-804	-833
32.0	-911	-980	-951	-980
34.0	-1049	-1127	-1078	-1127
36.0	-1205	-1284	-1245	-1294
38.0	-1666	-1735	-1695	-1754
40.0	-2244	-2274	-2215	-2244
40.0	-2283	-2352	-2303	-2352
42.0	-2656	-2734	-2666	-2685
43.2				

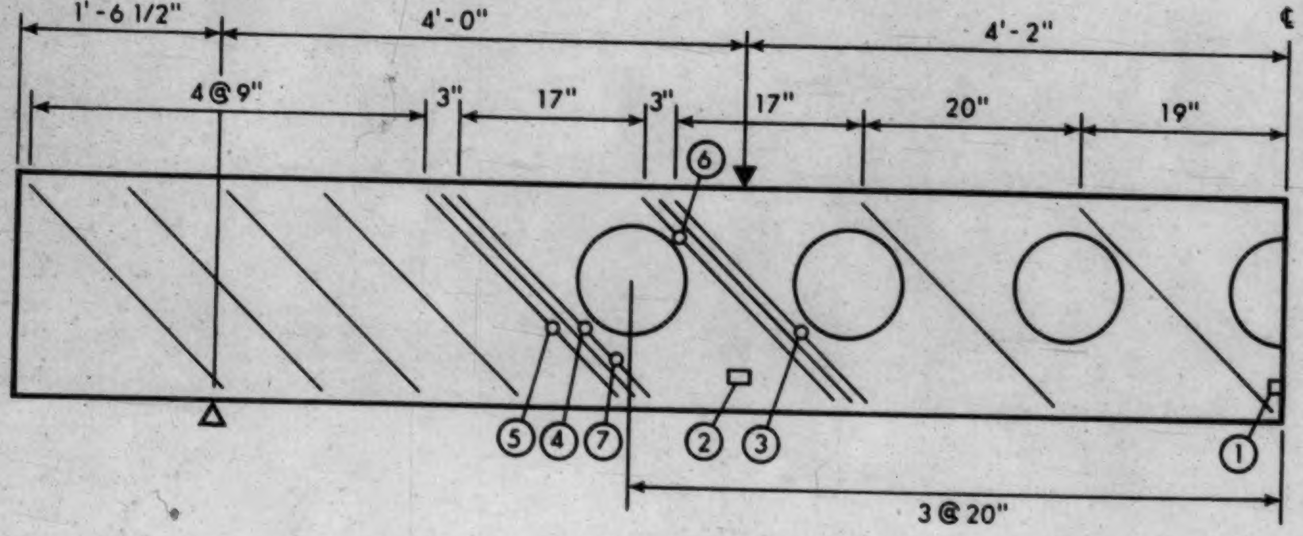
B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.8.3

DEFLECTION DATA BEAM AD-8

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
2.0	0.02	0.02	0.02
4.0	0.04	0.05	0.04
6.0	0.06	0.08	0.06
8.0	0.08	0.11	0.09
10.0	0.11	0.14	0.11
12.0	0.14	0.18	0.13
14.0	0.16	0.21	0.16
16.0	0.19	0.25	0.20
18.0	0.23	0.30	0.23
20.0	0.31	0.42	0.31
22.0	0.39	0.53	0.39
24.0	0.48	0.65	0.48
26.0	0.56	0.76	0.55
28.0	0.63	0.87	0.64
30.0	0.73	1.00	0.73
32.0	0.89	1.25	0.90
34.0	1.12	1.55	1.12
36.0	1.40	1.95	1.41
38.0	2.36	3.32	2.41
40.0	3.79	5.31	3.66
40.0	4.05	5.73	3.96
42.0	5.21	7.21	4.93
43.2		8.32	


1'-6 1/2"
4'-0"
4'-2"
℄
4@9"
3"
17"
3"
17"
20"
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②
③
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3@20"

FIGURE B.9 BEAM AD-9 REINFORCEMENT AND GAUGE DETAILS

TABLE B.9.1.1

STRAIN GAUGE DATA BEAM AD-9

LOAD (kips)	(1)	(2)	(3)	(4)
0.0	0	0	0	0
2.0	30	40	25	60
4.0	80	80	45	135
6.0	130	125	70	270
8.0	185	170	90	425
10.0	240	220	115	585
12.0	310	270	140	715
14.0	380	330	165	850
16.0	540	455	215	990
18.0	935	640	455	1100
20.0	1240	860	535	1190
22.0	1570	1125	595	1295
24.0	1880	1450	655	1405
26.0	2170	1745	725	1540
28.0	2530	2015	795	1675
30.0	2930	2280	845	1845
32.0	3750	3075	950	2055
34.0	4960	3725	985	2270
36.0	6790	4600	965	2375
38.0				

TABLE B.9.1.2

STRAIN GAUGE DATA BEAM AD-9

LOAD (kips)	(5)	(6)	(7)
0.0	0	0	0
2.0	35	35	15
4.0	70	90	40
6.0	125	180	70
8.0	195	300	95
10.0	285	400	140
12.0	355	500	180
14.0	475	615	260
16.0	640	730	430
18.0	765	850	705
20.0	845	950	890
22.0	935	1065	1130
24.0	1010	1170	1335
26.0	1080	1290	1540
28.0	1175	1420	1710
30.0	1310	1510	1915
32.0	1455	1655	2165
34.0	1600	1780	2410
36.0	1755	1865	3600
38.0			

TABLE B.9.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-9

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T. A.T.	1754 862	1509 823	1029 617	343 363	451 421
0.0	0	0	0	0	0
2.0	49	29	29	0	-20
4.0	98	88	59	0	-10
6.0	176	118	88	0	-29
8.0	235	176	108	0	-29
10.0	304	245	147	0	-59
12.0	382	294	176	0	-49
14.0	470	353	206	0	-78
16.0	568	431	245	0	-98
18.0	784	598	274	0	-69
20.0	1186	470	314	0	-78
22.0	1558	1166	402	10	-59
24.0	2107	1578	588	20	-69
26.0	2509	1901	774	20	-59
28.0	2940	2264	1000	39	-49
30.0	3391	2636	1215	69	-29
32.0	4655	3587	1784	147	29
34.0	5664	4498	2411	206	157
36.0	7262	6037	3410	333	353
38.0					

B.T.	BEFORE TRANSFER
A.T.	AFTER TRANSFER

TABLE B.9.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-9

LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	451	490	451	412
A.T.	451	470	421	421
0.0	0	0	0	0
2.0	-29	-29	-29	-39
4.0	-78	-59	-69	-69
6.0	-98	-98	-108	-108
8.0	-147	-147	-147	-147
10.0	-176	-186	-186	-186
12.0	-216	-225	-216	-225
14.0	-255	-274	-265	-274
16.0	-294	-314	-314	-333
18.0	-363	-372	-382	-402
20.0	-421	-431	-441	-461
22.0	-500	-500	-500	-539
24.0	-568	-568	-568	-617
26.0	-657	-627	-627	-686
28.0	-715	-706	-706	-755
30.0	-794	-784	-774	-833
32.0	-911	-902	-902	-960
34.0	-1049	-1029	-1029	-1098
36.0	-1254	-1225	-1235	-1303
38.0				

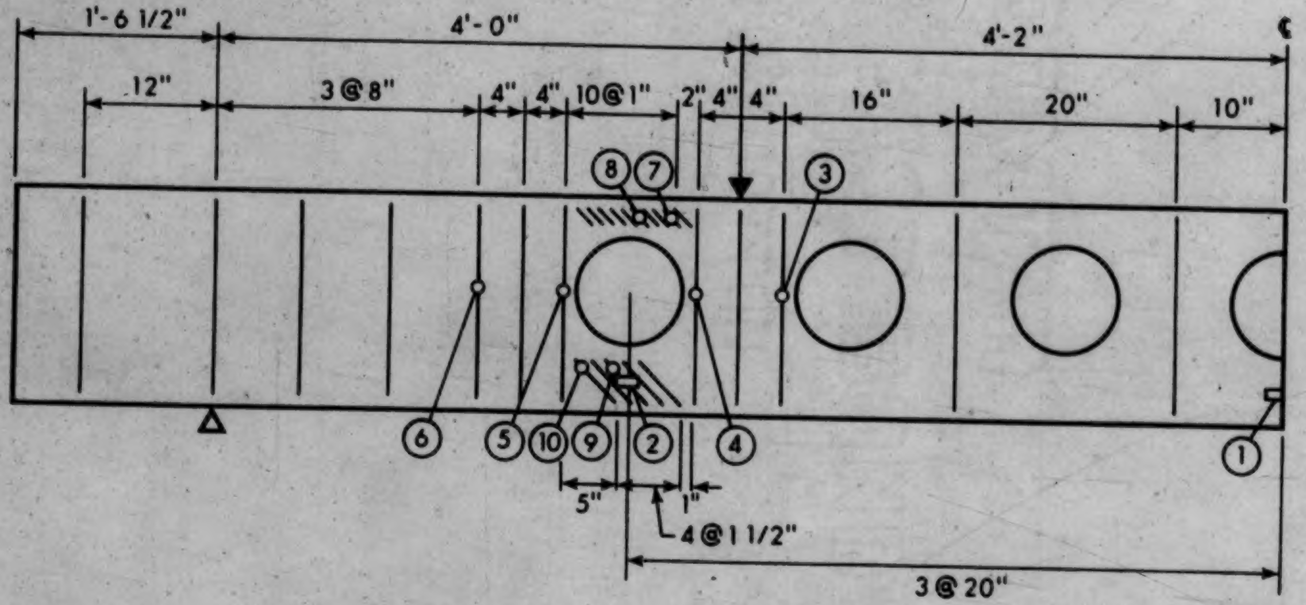
B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.9.3

DEFLECTION DATA BEAM AD-9

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
2.0	0.01	0.02	0.01
4.0	0.03	0.04	0.03
6.0	0.05	0.07	0.06
8.0	0.07	0.10	0.08
10.0	0.09	0.13	0.10
12.0	0.12	0.17	0.13
14.0	0.15	0.21	0.16
16.0	0.18	0.25	0.19
18.0	0.25	0.33	0.25
20.0	0.33	0.45	0.33
22.0	0.41	0.56	0.41
24.0	0.49	0.68	0.50
26.0	0.57	0.79	0.58
28.0	0.66	0.91	0.67
30.0	0.76	1.05	0.77
32.0	0.96	1.31	0.96
34.0	1.20	1.64	1.20
36.0	1.54	2.09	1.53
38.0			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4'-0"
4'-2"
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12"
3@8"
4"
4"
10@1"
2"
4"
4"
16"
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8
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10
5"
1"
4@1 1/2"
3@20"

FIGURE B.10 BEAM AD-10 REINFORCEMENT AND GAUGE DETAILS

8

TABLE B.10.1.1

STRAIN GAUGE DATA BEAM AD-10

LOAD (kips)	(1)	(2)	(3)	(4)	(5)	(6)
0.0	0	0	0	0	0	0
2.0		30	-5	-15	15	0
4.0		60	-10	-35	25	5
6.0		90	-20	-70	50	5
8.0		130	-20	-115	130	10
10.0		170	-20	-140	250	20
12.0		220	-20	-145	370	35
14.0		280	-20	-105	540	30
16.0		420	-25	20	610	25
18.0		585	-40	185	735	20
20.0		830	-45	465	885	15
22.0		1040	-60	720	1060	5
24.0		1265	-65	875	1205	0
26.0		1525	-65	1030	1360	-5
28.0		1855	-80	1160	1505	-5
30.0		2350	-95	1320	1730	5
32.0		3230	-120	1425	1905	1340
33.0		4750				

TABLE B.10.1.2

STRAIN GAUGE DATA BEAM AD-10

LOAD (kips)	(7)	(8)	(9)	(10)
0.0	0	0	0	0
2.0	5	5	25	15
4.0	15	15	50	35
6.0	25	25	90	65
8.0	35	30	135	100
10.0	45	30	175	145
12.0	50	35	215	185
14.0	65	50	265	335
16.0	120	65	325	550
18.0	210	90	460	665
20.0	325	150	665	885
22.0	455	290	795	1075
24.0	540	390	920	1290
26.0	610	495	1030	1575
28.0	725	635	1115	1760
30.0	885	785	1165	1885
32.0	1055	1020	1235	1980
33.0				

TABLE B.10.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-10

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1882	1637	1235	510	617
A.T.	1019	921	784	480	539
0.0	0	0	0	0	0
2.0	39	49	20	0	0
4.0	127	88	49	0	0
6.0	186	137	78	0	-10
8.0	265	196	108	0	-20
10.0	343	255	147	0	-39
12.0	421	333	186	0	-49
14.0	529	402	225	0	-59
16.0	676	510	255	0	-69
18.0	1294	892	480	0	-69
20.0	1872	1333	735	10	-49
22.0	2352	1695	970	20	-59
24.0	2842	2087	1245	69	-49
26.0	3391	2421	3538	206	-39
28.0	3920	2950	1911	421	0
30.0	4851	3704	2499	608	69
32.0	6272	4773	3283	970	206
33.0					

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.10.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-10

LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	598	588	539	392
A.T.	568	549	490	382
0.0	0	0	0	0
2.0	-39	-29	-29	-29
4.0	-69	-69	-69	-69
6.0	-98	-108	-118	-127
8.0	-137	-157	-167	-167
10.0	-176	-196	-216	-225
12.0	-216	-235	-255	-274
14.0	-265	-294	-314	-343
16.0	-323	-343	-372	-402
18.0	-402	-412	-441	-490
20.0	-470	-470	-500	-559
22.0	-539	-549	-578	-657
24.0	-617	-627	-657	-745
26.0	-706	-725	-755	-843
28.0	-804	-813	-853	-941
30.0	-921	-960	-1009	-1098
32.0	-1098	-1147	-1205	-1274
33.0				

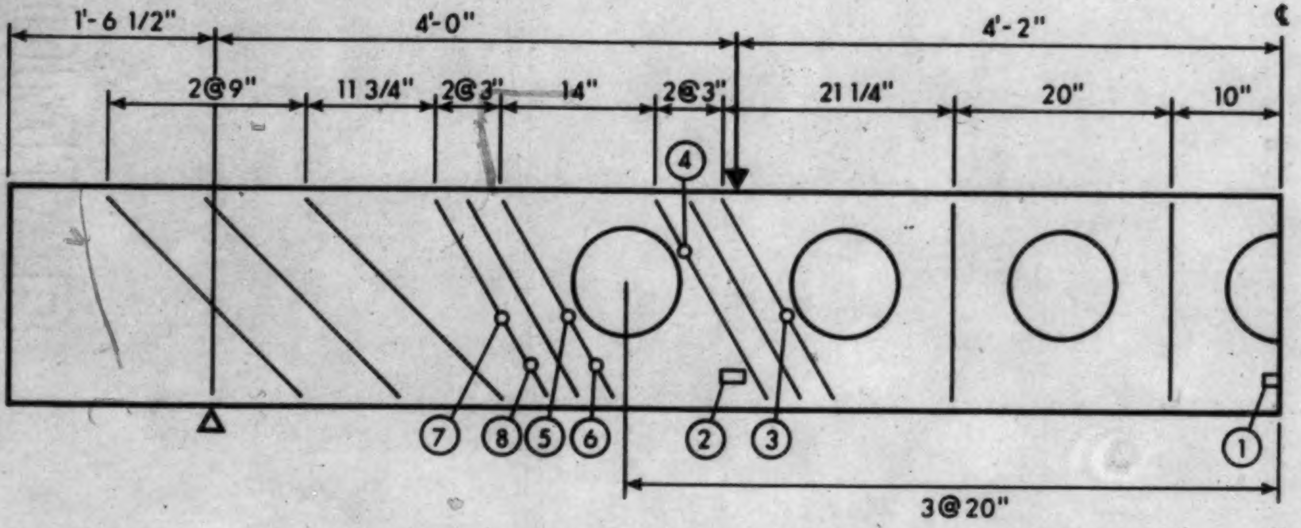
B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.10.3

DEFLECTION DATA BEAM AD-10

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
2.0	0.02	0.03	0.02
4.0	0.05	0.06	0.04
6.0	0.08	0.09	0.06
8.0	0.11	0.13	0.09
10.0	0.13	0.17	0.12
12.0	0.17	0.20	0.15
14.0	0.20	0.24	0.19
16.0	0.25	0.31	0.24
18.0	0.34	0.43	0.32
20.0	0.44	0.57	0.42
22.0	0.54	0.70	0.52
24.0	0.65	0.84	0.63
26.0	0.76	0.99	0.74
28.0	0.88	1.14	0.86
30.0	1.08	1.40	1.06
32.0	1.35	1.75	1.32
33.0		2.17	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4'-0"
4'-2"
℄
2@9"
11 3/4"
2@3"
14"
2@3"
21 1/4"
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3@20"

FIGUPE B.11 BEAM AD-11 REINFORCEMENT AND GAUGE DETAILS

TABLE B.11.1.1

STRAIN GAUGE DATA BEAM AD-11

LOAD (kips)	(1)	(2)	(3)	(4)
0.0	0	0	0	0
2.0	48	35	5	25
4.0	85	80	10	100
6.0	140	125	20	205
8.0	190	175	25	345
10.0	250	225	35	475
12.0	305	275	45	580
14.0	375	345	50	650
16.0	475	425	50	790
18.0	700	555	45	965
20.0	1185	815	5	1185
21.0	1350	935	15	1275
22.0	1535	1080	55	1385
23.0	1685	1225	75	1475
24.0	1835	1370	105	1530
25.0	1990	1555	140	1500
26.0	2160	1785	165	1495
27.0	2350	1935	185	1535
28.0	2500	2100	200	1565
29.0	2690	2270	215	1605
30.0	3005	2500	230	1620
31.0	3410	3010	245	1500

TABLE B.11.1.2

STRAIN GAUGE DATA BEAM AD-11

LOAD (kips)	(5)	(6)	(7)	(8)
0.0	0	0	0	0
2.0	35	10	15	0
4.0	100	30	30	5
6.0	185	50	50	10
8.0	315	70	80	20
10.0	425	95	110	30
12.0	540	125	145	40
14.0	655	215	195	55
16.0	705	540	265	90
18.0	810	810	340	120
20.0	925	1080	455	155
21.0	990	1195	515	170
22.0	1060	1335	560	185
23.0	1125	1445	635	195
24.0	1205	1575	775	215
25.0	1320	1735	875	240
26.0	1435	1895	945	295
27.0	1520	2020	1000	325
28.0	1630	2155	1075	350
29.0	1725	2300	1140	375
30.0	1755	2590	1235	415
31.0	1835			

TABLE B.11.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-11

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1460	1186	784		343
A.T.	657	568	441	216	294
0.0	0	0	0	0	0
2.0	59	39	20	20	-10
4.0	118	88	39	10	-20
6.0	176	127	69	10	-29
8.0	245	186	98	10	-39
10.0	314	225	127	20	-59
12.0	392	284	157	20	-59
14.0	470	343	186	20	-69
16.0	559	421	225	20	-78
18.0	715	519	265	20	-88
20.0	882	598	363	20	-98
21.0	1009	676	412	20	-98
22.0	1196	813	461	10	-88
23.0	1352	931	510	20	-88
24.0	1519	1127	598	39	-88
25.0	1705	1303	696	78	-78
26.0	1999	1548	862	147	-78
27.0	2254	1774	1019	225	-69
28.0	2528	1980	1166	304	-49
29.0	2754	2185	1313	372	-29
30.0	2969	2411	1480	441	-10
31.0	3254	2813	1784	578	39

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.11.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-11

LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	294	294	294	235
A.T.	294	265	284	235
0.0	0	0	0	0
2.0	-20	-39	-20	-29
4.0	-39	-69	-69	-69
6.0	-88	-108	-98	-118
8.0	-127	-157	-137	-147
10.0	-167	-196	-176	-186
12.0	-196	-225	-216	-235
14.0	-245	-265	-265	-284
16.0	-284	-314	-314	-333
18.0	-333	-363	-353	-392
20.0	-392	-421	-421	-461
21.0	-421	-441	-451	-510
22.0	-461	-480	-480	-549
23.0	-490	-510	-519	-578
24.0	-519	-549	-549	-627
25.0	-568	-578	-588	-666
26.0	-598	-617	-637	-715
27.0	-637	-666	-666	-755
28.0	-676	-706	-715	-804
29.0	-715	-745	-755	-843
30.0	-755	-735	-794	-892
31.0				

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.11.3

DEFLECTION DATA BEAM AD-11

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
2.0	0.02	0.02	0.02
4.0	0.04	0.05	0.04
6.0	0.06	0.08	0.06
8.0	0.08	0.11	0.08
10.0	0.11	0.14	0.11
12.0	0.14	0.17	0.14
14.0	0.16	0.20	0.16
16.0	0.19	0.24	0.19
18.0	0.23	0.29	0.23
20.0	0.30	0.39	0.30
21.0	0.35	0.46	0.34
22.0	0.40	0.52	0.39
23.0	0.44	0.58	0.43
24.0	0.48	0.64	0.47
25.0	0.53	0.70	0.52
26.0	0.58	0.77	0.57
27.0	0.63	0.84	0.62
28.0	0.68	0.91	0.67
29.0	0.73	0.97	0.71
30.0	0.80	1.06	0.78
31.0	0.91	1.21	0.89

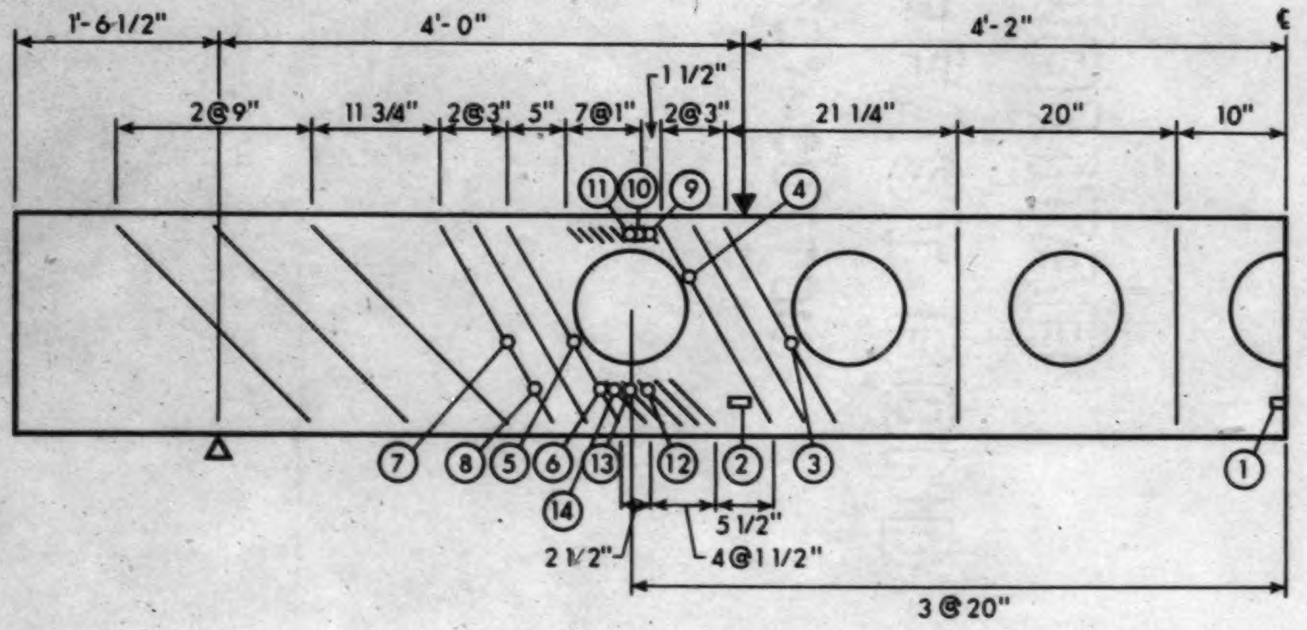
1'-6 1/2"
4'-0"
4'-2"
℄
2@9"
11 3/4"
2@3"
5"
7@1"
1 1/2"
2@3"
21 1/4"
20"
10"
11
10
9
4
7
8
5
6
13
14
12
2
3
1
5 1/2"
2 1/2"
4@1 1/2"
3@20"

FIGURE B.12 BEAM AD-12 REINFORCEMENT AND GAUGE DETAILS

TABLE B.12.1.1

STRAIN GAUGE DATA BEAM AD-12

LOAD (kips)	(1)	(2)	(3)	(4)
0.0	0	0	0	0
2.0	45	45	5	20
4.0	90	90	0	35
6.0	135	145	0	50
8.0	190	200	0	195
10.0	240	255	-5	340
12.0	305	320	0	480
14.0	365	395	0	625
16.0	455	480	-5	770
18.0	570	590	-10	970
20.0	895	870	-35	1170
22.0	1325	1105	-15	1360
24.0	1685	1405	55	1510
26.0	2005	1740	115	1670
28.0	2360	1985	155	1815
29.0	2535	2075	175	1855
30.0	2860	2455	190	1955
31.0	3390	2815	225	2090
32.0	4035	3035	270	2250
33.0	4460	3190	290	2210
34.0	5070	3530	345	2255
35.0	6050	4030	410	2950
36.0	7450	4375	470	9000
37.0	11200	4865	600	
38.0		5590	715	
38.0		6075	705	
39.0				

TABLE B.12.1.2

STRAIN GAUGE DATA BEAM AD-12

LOAD (kips)	(5)	(6)	(7)	(8)
0.0	0	0	0	0
2.0	30	15	15	10
4.0	60	35	30	10
6.0	105	55	45	15
8.0	195	75	65	20
10.0	445	100	100	40
12.0	625	140	140	55
14.0	775	190	180	80
16.0	910	265	235	110
18.0	950	720	305	160
20.0	1055	985	370	210
22.0	1150	1200	425	250
24.0	1290	1410	510	315
26.0	1450	1625	580	375
28.0	1655	1830	765	440
29.0	1780	1940	805	470
30.0	1890	2040	840	515
31.0	1960	2175	890	560
32.0	2000	2460	970	620
33.0	2035	4000	1030	670
34.0	2050	6200	1100	735
35.0	2060	10000	1220	820
36.0	2050		1450	855
37.0	2030		1590	930
38.0	2025		1675	1000
38.0			1720	1080
39.0				

TABLE B.12.1.3

STRAIN GAUGE DATA BEAM AD-12

LOAD (kips)	(9)	(10)	(11)	(12)	(13)	(14)
0.0	0	0	0		0	
2.0	5	10	5		25	
4.0	10	15	10		45	
6.0	15	20	15		80	
8.0	20	20	15		110	
10.0	25	30	15		150	
12.0	30	35	20		190	
14.0	40	45	30		250	
16.0	50	55	35		310	
18.0	70	75	50		330	
20.0	95	95	70		490	
22.0	130	120	90		770	
24.0	195	175	130		930	
26.0	260	250	190		1040	
28.0	620	615	480		1155	
29.0	745	695	590		1205	
30.0	850	760	645		1250	
31.0	1165	815	685		1310	
32.0	1700	915	735		1375	
33.0		1000	775		1425	
34.0		1100	835		1485	
35.0		1255	925		1550	
36.0		1405	1020		1590	
37.0		1630	1125		1605	
38.0		1925	1205		1585	
38.0		2395	1315		1485	
39.0						

TABLE B.12.2.1

DEMEC POINT STRAIN DATA (WEB) BEAM AD-12

LOAD (kips)	(1)	(2)	(3)	(4)	(5)
B.T.	1460	1235	764	255	314
A.T.	657	598	412	235	265
0.0	0	0	0	0	0
2.0	49	29	20	0	-20
4.0	98	78	39	0	-29
6.0	157	127	59	0	-39
8.0	235	176	88	0	-49
10.0	304	225	118	0	-69
12.0	372	274	137	0	-88
14.0	461	343	167	0	-98
16.0	568	412	206	0	-108
18.0	666	529	265	0	-118
20.0	784	676	343	0	-118
22.0	1441	1196	637	0	-108
24.0	1950	1617	902	10	-98
26.0	2372	1989	1166	59	-88
28.0	2832	2401	1480	167	-69
29.0	3067	2617	1627	225	-59
30.0	3352	2960	1000	314	-20
31.0	3861	3450	2332	490	39
32.0	4263	3969	2764	676	108
33.0	4567	4459	3165	843	167
34.0	5135	5096	3714	1078	255
35.0	6321	6145	4547	1450	382
36.0	8604	7909	5860	2068	627
37.0	14661	12867	9663	3793	1284
38.0					
38.0					
39.0					

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.12.2.2

DEMEC POINT STRAIN DATA (FLANGE) BEAM AD-12

LOAD (kips)	(6)	(7)	(8)	(9)
B.T.	274	314	284	225
A.T.	265	294	274	255
0.0	0	0	0	0
2.0	-29	-29	-29	-39
4.0	-59	-69	-69	-78
6.0	-98	-98	-108	-118
8.0	-137	-137	-147	-157
10.0	-176	-176	-186	-196
12.0	-225	-225	-235	-245
14.0	-265	-265	-274	-284
16.0	-314	-314	-323	-333
18.0	-353	-353	-382	-392
20.0	-421	-412	-441	-451
22.0	-490	-480	-510	-529
24.0	-559	-539	-578	-608
26.0	-637	-617	-647	-686
28.0	-715	-696	-725	-764
29.0	-755	-735	-774	-813
30.0	-823	-804	-853	-882
31.0	-902	-892	-941	-960
32.0	-980	-980	-1029	-1068
33.0	-1068	-1068	-1117	-1147
34.0	-1156	-1166	-1225	-1235
35.0	-1294	-1313	-1382	-1401
36.0	-1499	-1529	-1607	-1607
37.0	-2048	-2087	-2166	-2176
38.0				
38.0				
39.0				

B.T. BEFORE TRANSFER

A.T. AFTER TRANSFER

TABLE B.12.3

DEFLECTION DATA BEAM AD-12

LOAD (kips)	NORTH (in)	CENTRE (in)	SOUTH (in)
0.0	0.0	0.0	0.0
2.0	0.02	0.02	0.02
4.0	0.04	0.05	0.04
6.0	0.06	0.08	0.06
8.0	0.09	0.11	0.09
10.0	0.11	0.14	0.11
12.0	0.13	0.17	0.13
14.0	0.16	0.20	0.16
16.0	0.19	0.24	0.20
18.0	0.23	0.29	0.24
20.0	0.30	0.40	0.31
22.0	0.40	0.53	0.40
24.0	0.49	0.66	0.49
26.0	0.57	0.78	0.58
28.0	0.67	0.90	0.68
29.0	0.72	0.98	0.73
30.0	0.79	1.08	0.81
31.0	0.89	1.22	0.91
32.0	1.02	1.41	1.04
33.0	1.14	1.58	1.16
34.0	1.28	1.78	1.30
35.0	1.51	2.09	1.53
36.0	1.83	2.56	1.85
37.0	2.72	3.96	2.80
38.0	3.32	4.90	3.39
38.0	3.64	5.31	3.69
39.0		5.76	

APPENDIX C

DESIGN EXAMPLES AND NOTATION

C.1 Material and Section Properties

$f'c$ = 5000 psi

$f'ci$ = 4000 psi

fpu = 255 ksi

fy = 40 ksi

E = 28100 ksi

Eps = 28900 ksi

b = 20 in

bw = 4 in

d = 16 in

yb = 12.67 in

yt = 7.33 in

Ag = 114.25 in^2

Ig = 4583 in^4

Wdl = 0.12 kips per foot

Mdl = 72 in kips

fi = 174 ksi

fe = 140 ksi

Pi = 70 kips

Pe = 56 kips

C.2 Maximum Concrete Stresses at Transfer

Top at a support:

$$fc = \frac{Pi}{Ag} - \frac{Pi\ (d-yt)\ yt}{Ig}$$

$$= -0.358 \text{ ksi (tension)}$$

Top at centerline:

$$fc = -0.358 + \frac{Mdl\ yt}{Ig}$$

$$= -0.243 \text{ ksi (tension)}$$

Bottom at a support:

$$fc = \frac{Pi}{Ag} + \frac{Pi\ (d-yt)\ yb}{Ig}$$

$$= 2.291 \text{ ksi (compression)}$$

Bottom at centerline:

$$fc = 2.291 - \frac{Mdl\ yb}{Ig}$$

$$= 2.092 \text{ ksi (compression)}$$

The allowable concrete stresses at transfer by the ACI 318-71 Code, Section 18.4, are:

compression = 0.6 f'ci = 2400 psi

tension = $3(f'ci)^{0.5}$ = 190 psi

Because the allowable tensile stress is exceeded, reinforcement must be provided to resist the net tensile force on the section:

T = 9.1 kips

Steel Area required = 9.1/fy = 0.23 in^2

Four #3 bars in the flange provide an area of:

$4(0.11) = 0.44\ \text{in}^2$

C.3 Working Load Moments

The concrete stress in the bottom fibre of the beam can be expressed as:

$$fc = \frac{Pe}{Ag} + \frac{Pe\ (d-yt)\ yb}{Ig} - \frac{Mw\ yb}{Ig}$$

or, rearranging the terms:

$$Mw = Pe\left[\frac{Ig}{Ag\ yb} + d - yt\right] - \frac{fc\ Ig}{yb}$$

$$= 662.8 - 361.7\ fc$$

Thus for a maximum tensile stress at a working load of:

0 , Mw = 662.8 in kips

-424.3 psi, Mw = 816.3 in kips (Section 18.4.2(b))

-530.3 psi, Mw = 854.6 in kips (modulus of rupture)

-848.6 psi, Mw = 969.7 in kips (Section 18.4.2(c))

C.4 Ultimate Moment

$$fps = fpu - \frac{0.5\ Aps\ fpu^2}{b\ d\ f'c}$$

$$= 246.9\ \text{ksi}$$

$$Psu = Aps\ fps$$

$$= 98.8\ \text{kips}$$

Assuming that the longitudinal reinforcement at depths of 19 and 2.5 inches yields in tension, the total tensile force is:

$$T = 98.8 + 0.44 fy$$

$$= 116.4 \text{ kips}$$

Thus the depth of the equivalent rectangular stress block is:

$$a = \frac{T}{0.85\ b\ f'c}$$

$$= 1.37 \text{ in}$$

and the ultimate flexural capacity by the ACI 318-71 Code (assuming a capacity reduction factor of unity) is:

$$Mu = Psu\ d + 0.22\ fy\ (19 + 2.5) - T\ a/2$$

$$= 1690.3 \text{ in kips}$$

In addition to the equations prescribed by the ACI 318-71 Code for estimating ultimate flexural capacity, strain-compatability analyses were done on each of the beams using, for the most part, measured material properties rather than the design values. The stress-strain relationship of the prestressing strand was assumed to be bi-linear, with the inelastic portion extended to 281.25 ksi at 4% strain. Thus the total prestressing force could be expressed as:

$$Ps = 101.23 + 2.2555\ (es+ee)$$

where ee is the effective strain in the prestressing strand (in percent) given by:

$$ee = \frac{Pe\ 100\%}{Aps\ Eps}$$

and es is the estimate of the difference between ee and the strain in the strand at ultimate load.

Using the measured value of fy = 55 ksi, the force in the longitudinal reinforcement at different depths in the beam was also expressed in terms of es:

$$F(x) = A\,E\,\frac{x\,(0.3 + es) - 0.3}{d}$$

with a maximum of A fy. Finally the equivalent rectangular stress block parameters were also described:

$$c = \frac{0.3\,d}{0.3+es}$$

$$C = -0.85\,f'c\,(0.85 - 0.005(f'c - 4))\,c\,b$$

$$= \frac{-339.5}{0.3+es} \quad \text{(for Beam AD-1)}$$

$$a/2 = c\,(0.85 - 0.005(f'c - 4))/2$$

$$= \frac{1.884}{0.3+es} \quad \text{(for Beam AD-1)}$$

A sample set of calculation results follows for Beam AD-1:

Pe = 51.898 kips, ee = 0.45%

f'c = 5.3 ksi

assume es = 2.63%:

Fs = 108.18 kips

F(19) = 12.1 kips

F(2.5) = 9.76 kips

F(1) = -14.45 kips (compression)

C = -115.87 kips

Sum of axial forces = 0.28 kips

Mu = -0.643 (115.87) - 1 (14.45) +2.5 (9.76)

+19 (12.1) +16 (108.18)

= 1896.2 in kips

A third estimate of the ultimate moment capacity of the beams is a simplification of the strain compatability method. assume:

fps = 275 ksi

f'c = 5 ksi

and considering only the reinforcement below the prestressing strands:

Fs = 0.4 (275)

= 110 kips

F(19) = 12.1 kips (assume yielded)

C = -122.1 kips

$$a/2 = \frac{C}{2\ (0.85\ f'c)\ b}$$

= 0.718 in

Mu = -0.718 (122.1) +16 (110) +19 (12.1)

= 1902.2 in kips

C.5 Shear Reinforcement

For a beam with a 16 foot span and 4 foot shear spans:

Mdl = 46 in kips (moment at centerline)

$$Pu = \frac{(Mu - Mdl)}{4\ (12)}$$

= 34.25 kips

The critical section for shear stress is just outside the load point where:

$$V_u = 34.25 + 4\ (0.12)$$

$$= 34.73 \text{ kips}$$

and:

$$M_u = 1678.6 \text{ in kips}$$

By Section 11.5.1 the nominal shear stress carried by the concrete is:

$$v_c = 0.6\ (70.71) + \frac{700\ (34.73)\ 16}{1678.6}$$

$$= 274.2 \text{ psi}$$

Assuming a capacity reduction factor of unity:

$$v_u - v_c = \frac{34730}{4\ (16)} - 274.2$$

$$= 268.5 \text{ psi}$$

Using #3 double leg stirrups, the required spacing at the critical section is:

$$s = \frac{A_v\ f_y}{(v_u - v_c)\ b_w}$$

$$= 8.2 \text{ in}$$

Shear reinforcement calculations were also carried out at other sections of beams of both lengths by the method illustrated here, and also using the provision of a higher value of vc allowed under Section 11.5.2. The results of these calculations suggested that vertical stirrups spaced at 10 and 15 inches would be acceptable in the shear spans of the 16 foot and 20 foot beams respectively.

Because of the lack of information about shear reinforcement requirements in the presence of circular web openings the proportioning of stirrups in the test beams was done on an intuitive basis. By placing two, three or four stirrups in all posts in the shear spans, average spacing values of less than the design values were maintained, although it was understood that this was not a rationally complete approach.

Tentative calculations for the proportioning of upper and lower web stirrups were carried out assuming a net section approach and then that the upper and lower webs acted as compression and tension members respectively. This last method seemed the most rational although the values used were so arbitrary and indefinite that no further conclusion could be made. The small size of the upper and lower web sections had a more direct effect on the stirrup spacing chosen as it reduced the maximum spacing to the same order of magnitude as the minimum spacing based on ease of concrete placement.

C.6 Notation

A_g = area of the gross concrete section

A_{ps} = total area of prestressing strand

A_v = area of one stirrup

a = depth of equivalent rectangular stress block

b = width of compression face (flange)

b_w = thickness of web

C = total compressive force in equivalent rectangular stress block

c = depth to a fibre of zero stress

d = depth of centroid of prestressing strands

E = elastic modulus of non-prestressed reinforcement

Eps = elastic modulus of prestressing strands

ee = strain in prestressing strand corresponding to effective prestress

es = difference between es and strand strain at ultimate load

Fs = total force in prestressing strand

F(x) = force in non-prestressed reinforcement located at depth x

fc = general term for concrete stress

f'c = compressive strength of concrete

f'ci = compressive strength of concrete at transfer

fe = effective prestress after losses

fi = initial prestress after transfer

fps = calculated stress in prestressing strand at design load

fpu = ultimate strength of prestressing strand

fy = specified yield strength of non-prestressed reinforcement

Ig = moment of inertia of gross concrete section

Mdl = maximum moment induced by beam self-weight

Mu = ultimate flexural capacity of a section or moment at a section in a beam supporting its ultimate load

Mw = Working load moment

Pe = effective prestress force after losses

Pi = initial prestress force after transfer

Psu = force in prestressing strands corresponding to fps

Pu = ultimate jack load

s = spacing of shear reinforcement stirrups

T = net tensile force on an uncracked gross section at transfer

Vu = shear force at a section in a beam supporting its ultimate load

vc = nominal permissable shear stress carried by concrete

vu = nominal total shear stress corresponding to Vu

Wdl = weight of a one-foot length of beam

yb = distance to bottom fibre from neutral axis of gross concrete section

yt = distance to top fibre from neutral axis of gross concrete section